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THE JOURNAL OF
The Institution of Electrical Engineers

ORIGINALLY

The Society of Telegraph Engineers

TEMPORARY OFFICES: 1, ALBEMARLE STREET, LONDON, W. 1.

FOUNDED 1871

"TO PROMOTE THE GENERAL ADVANCEMENT OF ELECTRICAL AND TELEGRAPHIC SCIENCE AND ITS APPLICATIONS."

EDITED BY P. F. ROWELL, SECRETARY.

VOL. 56, 1918.

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NOTE.—On account of the shortage of paper, the publication of the following papers, which have been read at meetings, will be considered by the Council when conditions are again normal :—

Captain W. P. DIGBY : "Contract Prices during Demobilization."
E. C. MCKINNON : "Large Batteries for Power Purposes."
C. TURNBULL : "A British Electrical Proving House."

CORRIGENDA.

Vol. 55, pp. 494, 508, and 509 : Delete $(-1)^{k(N-1)}$ from Equations (5*d*), (5*e*), (6*b*), (6*c*), (26*d*), (26*e*), (27*a*), (27*b*), (29*b*), and (29*c*).

Vol. 55, p. 501, Table 3 : For "Multiples of 3 present" *read* "Multiples of 3 absent."

Vol. 56, p. 146, col. 2 : In Table A, col. 4, line 11, for "0·36450" *read* "0·03645."

Vol. 56, p. 205, col. 1, line 34 : For "7 p.m." *read* "7 a.m."

C. H. Wordingham.

PRESIDENT 1917-18

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 56. DECEMBER, 1917. No. 269.

INAUGURAL ADDRESS,

By C. H. Wordingham, President.

(*Address delivered* 8 *November*, 1917.)

Gentlemen,—

Introductory.

I am deeply sensible of the honour you have done me in electing me your President and am keenly appreciative of the confidence this action implies. The responsibility appears almost overwhelming when one's mind is directed to the large number of members concerned in the proper conduct of the Institution's affairs, the multifarious and often divergent interests affected and the peculiarly critical time in which we are at present. The conditions are constantly changing for the nation's life and for our industry, and we are faced with problems arising, some slowly and some abruptly, for which there is no precedent, problems which in any case cannot fail to be charged with momentous issues for our industry and perhaps for our Institution.

My dominant feeling is one of profound humility when I call to mind the giants of intellect and attainment who have preceded me in this chair. Men of science like Carey Foster and Crookes, men combining a foremost position in science with the commercial acumen necessary for engineering like Kelvin and John Hopkinson, and men more especially distinguished as practical engineers like Bright and Crompton, to select only a few representative ones. I can only assure you that I will give you of my best, and endeavour so far as in me lies, to justify the confidence that you have placed in me and to promote the honour and welfare of this Institution.

It is not unusual for a President to take for the main theme of his address a subject of which he has some special experience, and the fact that my work during the last 14 years has been in connection with a unique application of electrical engineering, namely, the equipment of ships of war, would seem to indicate that I should follow this course and describe to you the peculiar difficulties attending such work and the means taken to overcome them. Owing to the fact, however, that we are at present in a state of war, there is much that it would be inexpedient for me to mention, so that my account would necessarily be incomplete, and I have decided, therefore, not to follow this course, though I hope at some future time it may be possible to bring this section of my experience before you in some other form in more peaceful times.

I propose to take for the main subject of my address this evening the Institution itself; to consider how far it meets the needs of the profession and industry and what improvements can be made under its existing constitution; then to inquire whether it may not be possible to raise it to a far higher plane and make it much more potent in the development of electrical engineering. The Institution and the industry should be one, and if they are not it is our business to make them so. There are great problems before us, some present now and some that will confront us in the immediate future, and it will need the fullest co-operation and unanimity on our part as to the action necessary to enable them to be solved satisfactorily.

The Institution as now Constituted.

Its Legitimate Objects.

I will first address myself to a consideration of the Institution as at present constituted. I have been a member since 1884, and of those 33 years I have had the honour of serving on the Council in one capacity or another for fourteen, so that I have an intimate knowledge of its working. I have seen from time to time, with great regret, indications that many members are not wholly satisfied with the management of the Institution, and have heard expressions of opinion that it does not sufficiently represent the industry or look after its interests adequately.

These allegations are, in many instances, based upon ignorance of what the Council is doing, but more largely upon a want of appreciation of what it is possible for the

Council to do. It should never be forgotten that the Institution comprises in its members every electrical interest in the country; those interests are heterogeneous, and in many cases the interests of one section of the members directly conflict with those of another section. How then is it possible for the Council in the name of the Institution as a whole to represent adequately the material interests of one particular section without doing an injustice to another section? I have always held the view that the Institution should attend to the promotion of electrical science and its applications to engineering; it should promote research of every kind; it should encourage the spread of scientific knowledge and the improvement of engineering practice; it should set the highest possible standard of conduct and of attainment in knowledge and skill among its members, but it should not attempt to look after the commercial interests of any one section. It is often stated, in a somewhat sneering manner, that the Institution will not demean itself by looking after such sordid considerations as those involved in commercial pursuits, though its members, one and all, have necessarily to pocket their profits if traders, or their fees if consultants, and they have been observed to do so with considerable satisfaction when the receipts have been large.

No greater misrepresentation of the attitude of mind of those who see the limitations I have indicated could be made. The reason that I contend the Institution should not attempt to interfere with commercial matters is that it is impossible for it to do so efficiently. It is of the essence of the successful prosecution of commercial interests that those interests should be common and homogeneous, and I have always held most strongly that each section should organize its own association for the promotion of such interests so as to bring the greatest possible weight to bear by concentrating the whole action in one direction. This course was followed at an early stage by municipal engineers who formed the Incorporated Municipal Electrical Association. Much later there has been formed the British Electrical and Allied Manufacturers' Association to look after the manufacturing interests. Other Associations have been created for other interests which I need not enumerate. There can be no question whatever of the value that the two Associations I have particularized have been to the interests concerned, and this work has been accomplished simply and solely because each has been homogeneous and has only sought to serve the interests of the particular group of individuals affected. If each section is thus benefited it necessarily follows that the industry as a whole is advanced.

Secrecy of Council Proceedings.

I believe also that much apprehension arises from the fact that the proceedings of the Council are secret. Representations have been made from time to time to the effect that some account of each Council meeting should be communicated to members through the *Journal*, and an attempt has been made to publish those portions of the Council minutes which it has been thought might be communicated without detriment. I am afraid it is impossible effectually to meet this demand. Much of the matter which comes before the Council is of necessity confidential, and negotiations and communications take place which it would be impossible to publish without causing much mischief and defeating the objects in view. Matters apparently of the most harmless possible nature might, if published, give rise to much embarrassment, and in my view the only possible course is for members to trust those of their number whom they have elected to the Council and to believe that they are doing their best to ensure the good of the Institution and watch over the interests of its members.

Representation on Council.

This brings me to the very vital question of confidence of the members in the Council. It is an unfortunate fact that a very large number of members abstain from voting at the Council elections. The normal proportion of votes recorded to voting papers sent out is about 25 per cent. Obviously if members will not take the trouble to secure the return of members in whom they have confidence it does not lie with them to find fault later with the Council. Personally I am very fully impressed with the need for a thoroughly representative Council, and I should like to see some change made in the mode of its election which would ensure that each section of the members was directly represented thereon in proportion to the numbers in that section. For example, I should like to see the important groups, such as the telegraph and telephone members, the manufacturing members, the municipal members, the company supply members, and so on, each vote for their own representative or representatives, thus ensuring that those representing a specific interest were chosen by the whole body of members devoted to that interest. In addition I would have a certain number elected by the whole body of members independently of any group representation. There would undoubtedly be difficulties in the way of such a modification in existing practice, and the matter cannot be discussed adequately outside the Council, but I hope that when the next revision of the Articles takes place this matter may be given very full consideration with a view to making the Council as representative as possible in every way.

I know that successive Councils have tried their utmost to ensure the fair representation of every interest, but the fact remains that in some years one largely preponderates and in other years another, and under the existing system it is almost inevitable that it should be so. Whatever is done, steps must of course be taken to ensure continuity of management of the Institution's affairs, but at the same time there should be combined with this, as now, a constant succession of new blood.

Provincial Members.

Yet another matter which calls for attention is the undoubted feeling that London members have a decided advantage over those living outside London and abroad. Not only are they thought to get more than the other members, but in some quarters there is an idea that

there is a tendency for them to run the Institution. Every effort has been made by the Council in the past to remove any possible grounds for this feeling. The creation of the Local Sections, their representation on the Council, and the weight given to all suggestions received from such Sections have gone far to bring members outside London into full touch with the conduct of the Institution. The meetings held locally afford the same opportunities to members of meeting one another and of discussing Institution papers as are enjoyed by the London members; important papers read in London are read also at these meetings in addition to local papers, and there is considerable activity locally, stronger it is true in some districts than in others. The introduction of proxy voting, decided on last Session, goes far also to put all members on an equal footing, independently of geographical position.

It is of the utmost importance to the well-being of the Institution that any feeling of the kind I have mentioned should be wiped out; I confess it is difficult to see what more could be done, but I think it would be desirable occasionally to hold a full meeting with President and Council in some of the more important centres, such as Manchester, Leeds, Birmingham, Newcastle, and possibly Glasgow. It will be argued by London members that it is making a serious demand on them to ask them to go so far afield as Scotland, but the Scottish members may very well retort that it is just as far from Glasgow to London as from London to Glasgow, and I think the effort ought to be made. Not only would such a course quicken the interest of the members resident in the district, but it would serve the independent purpose of making the Institution better known to those outside the profession.

Work in London.

Turning now to London itself we may well inquire whether the Institution is doing all that it can for the advancement of its legitimate objects. Many members think that it is not, and I am afraid there is some ground for their doubts. This year we are peculiarly handicapped through the commandeering of our building by the Government. I confess it is a very severe disappointment to me personally that it will be impossible to try any of the experiments that I should have liked to see tried during my year of office. I have often felt that the large sums of money invested in the fine building that we possess on the Embankment have not brought in the return in usefulness that they should. The load factor of the building is painfully low, and the stand-by space in the shape of lecture theatre, common room, library, etc., is such as would cause consternation in the mind of a central station engineer. It is true that the lecture theatre is often lent to other societies, but how often is it filled by the members of the Institution? For what proportion of the members is the common room a place of rendezvous? And how many members ever enter the library or avail themselves of the magnificent collection of books therein? When one sees the extraordinary success of such an institution as the Manchester Engineers' Club in bringing together so many different kinds of people interested in engineering and in initiating useful schemes for the good of the industry, one cannot help asking oneself why it is that something of the sort cannot be done and done on a far larger scale by the Institution. It is true that Manchester is an altogether exceptional centre, but there are a great number of electrical engineers within a very moderate radius of Charing Cross, and if only the right scheme could be hit upon I am convinced that the Institution could be made an active centre of everything electrical. Even country members are often in London, and they would soon flock to the Institution if they knew they would meet there the men they want to see.

Without claiming to be able completely to solve this question, I would put forward a few suggestions which I think might be useful.

Informal Discussions.

In the first place, there seems to be something about the ordinary formal meetings which is found to be forbidding in some way to many members, more especially to the younger ones, and there is a want of the sociability and willingness to take part in the discussions which one finds in most of the local centres. Now that meetings have to be held at 6 p.m. I should like to see arrangements made for the meeting to be followed by an inexpensive dinner. This would suit the convenience of many members living out of town, and it would unquestionably promote acquaintanceship between members and greater familiarity among them.

Then, again, I think short informal meetings, at which points of difficulty or special and immediate interest could be discussed in a more or less conversational manner, would be of great utility. Often a burning question arises, frequently at short notice, and it would be of inestimable benefit if the matter could be thrashed out at a meeting at which everybody concerned would be able to put forward his views and hear what his neighbours thought about the matter. Such meetings would encourage the younger members to come forward. Many, who though possessing valuable knowledge and ideas, are too diffident to write papers or join in formal discussions, would take part in proceedings of this kind, and while adding to the usefulness of the meeting would be encouraged, once the ice were broken, to join in the ordinary meetings. I am confident that the progress of the Institution will be greatly helped by interesting the younger members in its doings, and every possible means should be taken to effect this end. As an indication of the sort of subject I have in mind for such discussions I would instance some new Standard Specification of the Engineering Standards Committee, or a set of Rules prepared by the Institution, such as the Regulations for the Electrical Equipment of Ships in hand at the present moment. If these were discussed in their draft form before final publication most valuable assistance would be given to the Committee charged with preparing them, and the Specification would be better understood by members and more generally acceptable to them when issued. Again some important Government action affecting electrical engineering might well be discussed in this manner, or the policy

to be followed by the industry as a whole towards such a question as the adoption of the metric system. More intimate matters affecting the management of the Institution itself might often be talked over with advantage. Were such an opportunity available many subjects would arise for discussion.

Special Lectures.

Many of the older members of the Institution completed their training more years ago than they care to remember, when electrical science was far behind its present development, and, although each will have kept well up in his particular branch of work, it is impossible for him to follow every development that takes place, and very often an entirely new branch grows up with which he has only a bowing acquaintance. It would be of extreme value if the Institution were to arrange for a series of lectures on special subjects by experts in those subjects setting forth what has been accomplished in the particular branch concerned and giving a general idea of the present position of knowledge. For example, electric furnaces have developed to an extraordinary extent during the last few years; electrical theory has undergone many modifications and much development; a practically new field in electrical cultivation is being opened up, and many other examples will suggest themselves.

Workmen.

Again I should like to see something done with a view to interesting the enormous army of men not qualified to become members in any grade of the Institution, but on whom much of the welfare of the industry depends. I refer to the workmen class. It should be possible to awaken in these men, many of whom are exceedingly intelligent, a desire for a better knowledge of the principles underlying their work. We have seen attempts made by individual firms to promote such interest by the holding of examinations and the offering of prizes; surely if an individual firm can create interest in this manner it should be possible for the Institution to do far better. The opportunity could be utilized for taking up economic questions with a view not only to educating workmen in the scientific principles of the work on which they are engaged, but also in the economic questions which are vital to the success of the industry.

General Public.

The Institution might with advantage come out of its shell and cater for the education of the general public in electrical matters. Popular lectures on the lines so successfully followed by the Society of Arts and the Royal Institution would do much to spread an elementary knowledge of electrical subjects and to make the public realize the advantages of electrical appliances. Lectures which gave solid facts to individuals of ordinary common sense would, I believe, do far more to promote the objects sought by so-called "publicity campaigns" than any amount of exaggerated statements, or of posters and illustrations, imagined by their authors to be humorous or arresting. Even children might be catered for by suitable lectures, say at Christmas time, accompanied by demonstrations of electrical toys and simple educational apparatus.

Permanent Exhibition.

This branch of the work might be supplemented by a carefully organized permanent exhibition of electrical appliances, these being constantly changed, and demonstrations of new apparatus arranged for. It ought to be a well understood thing that if any new useful electrical invention is brought out it can be seen at the Institution as a matter of course, and an explanation of its action be forthcoming.

Conversaziones.

From time to time conversaziones might be held on the lines of those given by the Royal Society for many years past. At these members would bring forward their latest achievements and give demonstrations of their discoveries.

It may be argued that such a programme as I have very broadly outlined would involve an enormous amount of work, and this I do not for one moment deny, but, like an individual, the Institution can only effect useful results by work, and unless we put the energy in we shall most certainly fail to get anything out.

Research.

So far I have dealt with the more or less public action of the Institution, but much more ought to be done than has hitherto been effected in the direction of research. A useful beginning has been made, but there is a practically limitless field to be covered. Speaking from a very intimate experience of the work, I am of opinion that it cannot be looked after adequately if it be dependent solely upon the efforts of overworked members of Council, who can only give portions of their time spasmodically to the work. In my opinion the Institution ought to have one or more well-paid men of the highest scientific attainments to look after technical questions such as research and the organization of the various fields of activity which I have indicated.

The Institution Reconstituted.

Royal Charter.

I have spoken so far of what might be done by the Institution under its existing constitution, but I feel most strongly that it is seriously and unnecessarily handicapped by being constituted under the Companies' Acts. I am ambitious for the Institution; I want to see it occupying its proper place in the life of the nation and in the enjoyment of a Royal Charter which shall confer on it those powers which alone can enable it to take effectual action for the good of its members and, I may add, of the general public whom they serve.

Mandatory Powers.

It is a matter of common knowledge that the electrical industry has suffered severely in the past from ill-advised legislation, but it is not, perhaps, so widely

recognized that it has been seriously hampered by the absence of mandatory powers appertaining to any body within the profession. The feeling is widespread that compliance with some standard of education, training, and experience should be enforced before a man is allowed to call himself an electrical engineer, and that adherence to certain standards of professional conduct should be a necessary condition of his continuing to practise; at present anyone can call himself an electrical engineer, and no one has the right to object; nay, more, if someone chooses to call himself a member of this Institution there is no legal process by which we can stop him.

The position in regard to the promulgation of rules regulating electrical practice in essential particulars is most unsatisfactory. The Institution has drawn up such rules, but can give them no mandatory force, with the result that those contractors who recognize their necessity and value, and who wish to support the Institution loyally, are placed at a serious and unfair disadvantage in competing with less scrupulous firms who flout the rules, knowing that they can do so with impunity. Bad work is thus put in to the detriment alike of the sound contractor and the public, while the reputation of the industry suffers and its progress is retarded.

Most engineers are agreed as to the imperative necessity of standardizing practice in regard to manufacture, both as regards the rating of machinery and the interchangeability of parts of articles in common use, but although an immense amount of work has been done in preparing such standards no power whatever exists to enforce them, and in the absence of compulsion, which would put all manufacturers on an equal footing, firms who would gladly comply with the requirements hesitate to incur the expenditure necessary to bring their practice into line with them, while others, taking a narrow and short-sighted view, deliberately refuse to adopt them. The result is that the cost of manufacture is unnecessarily high and users suffer inconvenience from the diversity of practice, the spread of the use of electrical appliances being retarded in consequence.

The absence of any authority which has the power to say whether a given article conforms with certain regulations or standards, or attains some specified degree of excellence, is a serious impediment to trade, especially to British trade abroad, which is perhaps somewhat imperfectly realized. I shall enlarge on this a little later.

I have indicated a few of the directions in which powers are required. The Medical and Legal professions already have the power to regulate the admission of new members to their ranks and to expel those unworthy to continue in them, and there can be no inherent reason why the Engineers on whom depend the lives of countless thousands of the general public should be denied similar powers.

Joint Action of all kinds of Engineers.

I am aware that there are serious difficulties in giving effect to the views I have enunciated. In the first place, electrical engineers, though they touch at one point or another the work of almost every other class of engineer, are but one of several important groups. Distinct from them are mechanical engineers and those who practise civil engineering in its more restricted sense of bridge and harbour construction, road-making, railway construction, sewage works, and similar undertakings. It is difficult for one section of engineers to obtain powers not sought by other sections, and unquestionably our efforts ought first to be devoted to carrying with us those other bodies, such as the Institution of Mechanical Engineers, the Institution of Naval Architects, and more especially that mother of Institutions, the Institution of Civil Engineers, to which we, as an Institution, owe so much, and members of which were our first founders when we were but a Society and were fostered by the Civils. The fact that we have grown so and have become independent should not blind us to its prestige nor make us forgetful of the benefits we have enjoyed; rather should we look forward to greater benefits to be derived from cordial co-operation and an entry as one of several partners junior to the Civils into a solid combination of engineering interests. If our efforts to promote this joint action fail, then we must still try what we can do on our own account, but concerted action must unquestionably give the best results. Engineering in the widest sense would then be placed on the same footing as other professions, and be similarly recognized by Government. The powers and privileges granted would be delegated to, and exercised by, the several Institutions for the branches which they respectively represent.

In seeking for powers such as I have indicated I do not wish it to be understood that I think they should all necessarily be vested entirely in the Institution. The powers relating to the entry and continuance in the profession should certainly be granted to the Institution and to no one else, just as the Medical Council controls doctors and the Law Society solicitors, but the rules for regulating engineering practice and standards may well require some collateral Government action to give them force after the Institution has formulated them.

Elasticity as to Qualifications.

Electrical differs from all other kinds of engineering in the extraordinary variety of the operations included in the general term. We have professional men planning works and corresponding to the typical civil engineers of Great George-street. We have large manufacturing firms, for example the large cable companies whether laying submarine cables or constructing networks of underground mains for cities, corresponding to the large contractors for civil engineering works, such as harbours or bridges. We have municipal engineers whose duties in many respects resemble those of borough surveyors. We have manufacturers of heavy plant for driving rolling mills, propelling railway trains, and all kinds of power work corresponding to those engineers who form the bulk of the Institution of Mechanical Engineers. At the opposite end of the scale we have makers of telegraphic and telephone

apparatus of extreme delicacy and instrument makers who correspond to those who are members of scientific rather than engineering societies. We have electro-chemists and makers of batteries whose vocation nearly approaches to chemical industry. New branches of work are daily opening up, such as electric furnaces which trench on the great steel industry, and electro-culture at which point we touch farming.

The point I wish to make is that no other Institution has so many and such varied interests to represent, nor has any other profession need for anything approaching the elasticity as to the qualifications to be demanded of those entering its ranks as our own. It is for these reasons, probably, in large measure that the present unsatisfactory state of affairs has arisen, but the difficulty of the problem only makes its solution the more imperative.

All Interests federated under the Institution.

Owing to the importance of certain sections, influential bodies outside the Institution have grown up. I have already stated my conviction that it is eminently right and proper that they should be formed to look after those members who have common material interests. It is, however, equally important that there should be no overlapping, and that they should confine themselves to those branches of work which the Institution cannot do so efficiently as they. I deprecate most strongly anything in the nature of rivalry. The ideal that I look forward to is a strong Institution, endowed with a Royal Charter, recognized as the embodiment of the whole industry as far as those outside it are concerned, invested with full powers as to the educational qualifications to be possessed by all grades of workers in the profession and industry from the highest to the lowest, and effecting under its ægis the federation of all other associations connected with the multifarious branches of electrical work.

I may here point out that we cannot expect more than one body to be recognized by the Government and the public as standing for the electrical industry, and it is vital to all concerned that such recognition should be bestowed on an association that is truly representative of the entire industry, and that has the maximum weight of authority and numbers behind it; this the Institution would possess if constituted and worked on the lines I have indicated.

I do not underestimate the difficulties in the way; I do not imagine the ideal will be attained in a day nor in my year of office, but I feel strongly that a beginning should be made at once and I see no reason, if all will pull whole-heartedly and loyally together, why the ideal should not be realized.

It must be borne in mind that most of the members of other electrical associations are already members of our Institution, many of them active ones, and if they were satisfied that we were in a position authoritatively and effectually to help their respective organizations there can be little doubt that they would support the federation I suggest and work unreservedly to assure the Institution occupying the leading position that it should, sinking all rivalry if such rivalry exists.

Broad Lines of Constitution.

It would be futile to attempt to enter into any detail here. Broadly, my view is that each section should have its own association to look after its commercial interests, such associations being formed if not already existent for a particular branch, and that each should be represented directly in appropriate proportions on the Institution's Governing Body. The Institution to be given a definite status by the Government and recognized as the only body representing electrical engineering; the Institution to control entry into the profession, and all regulations on electrical matters to be issued at its instigation or in accordance with its advice. Grants in aid of research or other national purposes to be entrusted to the Institution for administration.

It may be argued that the Institution, even though modified in its constitution in the manner suggested, would still have the difficulties I emphasized earlier in my Address in regard to the discordant commercial interests of different sections of its members. To some extent this is probably true, but its authoritative position would enable it to compose many differences which it is now powerless to influence and in very few cases would it be found necessary for any special Association to take independent action, but in the last resort this could be allowed without detriment to the scheme.

Research.

Scientific Research.

With a strong Institution such as I have depicted, the field of usefulness would be enormous and the potentialities almost beyond calculation. One of the most important matters demanding attention is research. Scientific research on purely academic lines should be closely pursued, for, after all, in the past it is from such work, having apparently no commercial application, that the industry itself and many of its most lucrative developments have sprung. In the men who devote themselves to pure science, in the professors, in the students just out of their college courses, we have within our membership a magnificent personnel for such work and if they were organized, the results of their discoveries being brought directly before manufacturers and the needs of manufacturers brought before them, there can be no doubt that we should progress by leaps and bounds. Investigations of this kind need laboratories, and by utilizing those that already exist the facilities at our disposal would be immense.

Industrial Research.

Equally important is industrial research, by which I understand the development of scientific discoveries in such a way as to found on them industrial processes, and the experimental development of new methods of manufacture to attain definite desired results. Here the work must fall on manufacturers who alone have the facilities and the experience required for the prosecution of the work.

Scientific and Industrial Co-operation.

The point I wish to make is that the workers at both kinds of research should be welded together so as mutually to assist one another, and so that the manufacturers may have a call on the highest talent in the country, while the scientific seeker after discoveries may avail himself of the resources of the manufacturers to test any promising inventions he may make. Such co-operation must tend to give far better results than any independent efforts of one class of worker without the other.

Scientific Laboratories.

While advocating the utilization and co-ordination of those facilities which exist, I do not of course overlook the need for supplementing them where incomplete by other laboratories. In the National Physical Laboratory we have magnificent facilities for scientific investigation of the highest class, and now that it has been, or is about to be, taken over by the Advisory Council for Scientific and Industrial Research it may be hoped that it will in future be supplied with adequate funds by the Government. In such event it would probably be unnecessary to establish any additional laboratory for scientific research, since in conjunction with the facilities at the University and Technical Colleges of the country ample provision would be made for this class of research.

Objects of Research.

Industrial research stands on a very different footing in every way. To begin with, the objects in view of the worker differ fundamentally; apart from his desire to advance the world's knowledge, the experimenter in pure science is usually chiefly concerned with his reputation and is eager to publish his results to the world so as to get the credit of his discoveries. The industrial experimenter, on the other hand, has for his main purpose the improvement of his manufacturing methods and the securing, if possible, of profitable monopolies. The last thing he desires, as a rule, is to publish his hardly won knowledge for the benefit of his trade rivals, British and foreign.

This fundamental difference in the objects of the workers involves important considerations in the promotion of research out of national funds. If industrial research is to be of real value to the nation it is essential that much of the work done shall be kept secret and only imparted to those who will directly utilize the information obtained for the benefit of British trade. Obviously it would be folly to spend public money and employ the abilities of some of the ablest men in the country in the development of new or improved processes of manufacture and then to publish the results for gratuitous use by the enemies of British trade. Fortunately, this has been recognized from the first by the Advisory Council of Research, to whom the administration of the funds voted by Parliament has been entrusted and much valuable work has been, and is being, done to enable British manufacturers to produce articles formerly obtained from abroad, such articles in many cases being of superior quality to the foreign ones.

Property in Results.

Industrial research bristles with difficulties, not the least being the problem of the ownership and patenting of new discoveries or processes. If these are obtained by the employment of public funds it may be argued that they should be the property of the nation; on the other hand the funds would have been of no avail without the genius of the discoverer, and he is obviously entitled to a substantial share of whatever profit is made. These problems admit of solution in many instances and are in fact being solved, but their existence must be recognized. Nevertheless, it would seem certain that in the future as in the past much industrial research will be carried out by individual firms or groups of firms without Government aid of any kind. In this way the benefits of discoveries will be retained wholly for those originating them.

Industrial Laboratories.

Industrial, differs from purely scientific, research also in the scale, and in consequence the cost, of experiment. The concentration of the manufacturing interests in the hands of one or two gigantic companies in America and Germany has enabled those companies to develop their facilities for research to an extent that is clearly impossible in this country where a much smaller volume of manufacture is conducted by a multiplicity of firms. In consequence, what facilities exist for industrial research are partial, unco-ordinated, duplicated and incomplete. There is, therefore, a crying need for the establishment of one or more fully equipped laboratories on a large scale for the investigation of industrial problems. Such laboratories will need the generous support of the Government and the manufacturers. Without setting up the gigantic monopolistic concerns of other countries we can secure results as good as, and probably better than, they by the co-operation of our smaller companies in which individual initiative and ability have greater play.

I have spoken of scientific and industrial research as though the two were quite distinct from one another, but obviously there can be no sharp dividing line between the two; they merge the one into the other and the borderland is wide and indefinite. Much highly scientific work must be done by the industrial experimenter, and the man engaged on research in pure science will often have the practical application of his work in view. Nevertheless the broad distinctions I have drawn are real and exist in fact.

Finance.

It may be well here to point out that research alone will not suffice to ensure industrial progress in this country, however extensive the facilities that may be provided. In point of fact much research and many discoveries have taken place here in spite of the unfavourable conditions. The cleverness of the Germans of which we have heard *ad nauseam* has lain not in their originality or inventiveness but in their quickness in appropriating other people's inventions; they have provided the money to tempt away to

Germany the English inventor whose work was received with coldness and suspicion by those of his fellow countrymen possessing the capital necessary to secure the fruits of his labour and who would not provide the funds. Hundreds of cases could be cited in illustration. I may mention one that came under my notice quite recently. A material widely used in electrical apparatus could before the war only be obtained from Germany. A firm of manufacturers in this country discovered that the whole of the plant and process for producing this material was the invention of an Englishman; they were fortunate enough to get into touch with him, with the result that they are now putting down plant which is a duplicate of that which he had designed for his German employers and the material will now be made in this country of exactly the same quality as, or probably better than, that formerly only obtainable from Germany. We have the discoverers and inventors in this country and always have had them; if we give them facilities as good as those possessed by our rivals and back them up with financial support, the possibilities before us are unlimited—but we must do both.

Individual Effort.

Though we may justly hope much from co-operation and State-aided research, there can be no doubt that a large proportion of the advances made will be due to individual effort and researches carried out in the works of single firms working solely in their own interests. The instance just cited is a case in point; the manufacturers referred to worked on independent lines and succeeded in making the material, while an influential Committee working for a long time on the same problem has so far, I believe, produced little or nothing. It may be objected that the success was due to the happy chance of finding the inventor and not to private research; the fact, however, remains that it was the private firm that got the thing done.

National Electrical Proving House.

A consideration of laboratories leads me to another matter to which I have already very briefly alluded, namely, the establishment of an institution which shall be in a position to say authoritatively whether certain standards have been complied with and to give a hall-mark to British manufactures. It has long been a cherished ambition of mine to see established such an institution for which I have suggested the name of National Electrical Proving House. In 1899 I read a paper * before the Institution in the course of which I described a local attempt which I had made, with a considerable measure of success, to test samples of fuses, switches, and similar fittings with a view to certifying that they reached a certain standard of excellence, and I strongly advocated that the Institution should take the matter up and carry out the idea on national instead of local lines. My proposals, however, met with considerable opposition and nothing was done. Previous to 1913 a serious situation had arisen in connection with British trade in Canada on account of the non-existence of such an authority as I have indicated, British manufacturers having to send their goods to Chicago to be tested and passed before they could be sold in British Canada! In view of this the Council referred the matter to a special Committee, but owing to the outbreak of war the question was allowed to stand over. After waiting for about a year and a half I sent to the technical Press, with the sanction of the then President, the proposals which I had made to the Committee. I had outlined a definite scheme and my proposals met with considerable support and were favourably received by the I.M.E.A. and the B.E.A.M.A., but nothing happened. Since the war, the reality of the need which I first pointed out 18 years ago has been appreciated and there is clear indication that the proposal commends itself to manufacturers and, with a courtesy and consideration which I highly appreciate, members of the B.E.A.M.A. have asked me to bring the matter forward at the Institution during my year of office. I have given the details of the scheme a good deal of consideration, but this is not the occasion on which to enter into them; a Committee of the Council has already been instructed to report on the matter and they have recommended the setting up of a Committee representing the interests concerned. When this Committee has drafted outline proposals an opportunity will be given for the matter to be fully discussed by the general body of members, after which I hope that definite and adequate steps may be taken before the close of the Session to set up an authority which shall be able to certify whether an article is or is not in conformity with a given standard of excellence and shall give it a hall-mark which shall be recognized throughout the world as a guarantee of British origin and British excellence and reliability.

* C. H. WORDINGHAM: "The Regulation of Wiring Rules," *Journal I.E.E.*, 1899, vol. 28, p. 166.

INFLUENCE OF THE WAR.

The War a Solvent.

The war cannot fail to have a profound effect upon all industrial enterprises. It has been primarily a mighty solvent, dissolving many obstacles to progress that formerly existed and, at the same time, some of the bulwarks under which we were sheltered. It has made men's minds fluid so that many deeply rooted prejudices have been washed out of the soil in which they grew and it has loosened the surfaces hardened by habit and custom so that new ideas may take root. Let us hope also that it may hold in solution principles of cohesion that shall in due time cement together all that is good in our Empire into a solid and coherent whole. It lies with those of us who may survive this awful deluge of death and destruction to watch over the crystallizing out of the elements now in solution and to direct the process to the betterment of our own nation, and of mankind in general, so that future generations may gather, what is to us, the "far off interest of tears." The task is an appalling one, for many of our problems are without precedent and we must rely upon principles of justice, equity, and forbearance in shaping our course—forgiveness

too will find a place if, and when, its necessary antecedents of true repentance and amendment appear.

Government Assistance.

The political measures for the furtherance of trade can find no place in an address such as this. I will only remark that while the potentialities for good immanent in the Government are enormous, they should be directed towards assisting industries and not be employed in interfering with them. Each industry knows best its own business and requirements and how its interests can be furthered. It is for the Government to give such aid as is possible and to harmonize the interests of different industries and of industrialists with those of other classes of the community when those interests conflict with one another. Legislation, however well-intentioned, which tells a man how he is to manage the work in which he is expert, or which interferes in the relations between the individuals engaged in it, is apt to be mischievous. It is the proper function, however, of Government to utilize the power of compulsion vested in it in order to ensure that impartial justice is done and that no one section of the community, however powerful by riches or numbers, oppresses any other.

Nationalization of certain industries is not infrequently mooted, but I venture to think that in no case should the Government undertake any business of a commercial nature. It starts with the handicap of being regarded by most as the legitimate prey of all who can get the better of it, and it is further handicapped by the impossibility of employing those methods which make for success in obtaining business and executing it satisfactorily. I refer more especially to individual effort and initiative, untrammelled power for those engaged in the work to decide and act quickly, freedom and secrecy in negotiations, and finally the important and perfectly proper incentive of personal profit.

The chief ways in which Government can assist industry are the safeguarding of British interests abroad so that the British trader may be at least on an equal footing with those of other nationalities in foreign markets; the shielding of young industries in this country from foreign competition during the period of their infancy and from unfair and State-aided competition when adolescent; the conservation of natural products of the Empire for the exclusive use of British manufacturers up to the maximum quantities required by them, due regard being paid also to a reasonable extent to deferring ultimate exhaustion; the removal of all obstructive and injurious legislation; and, finally, the collection of really useful information as to foreign markets not available to traders by their own unaided efforts and its dissemination without delay among those concerned. I have already indicated the good that I think might be done by the Government in connection with engineering by conferring wider powers on the existing engineering Institutions.

Co-operation.

Although there are ways in which the Government can help, and help effectually, it must receive guidance from the industry as to what is required and it is from the industry itself that the initiative and the main portion of the work in securing success must come. The problem of the promotion of British trade after the war is one which has come in for an immense amount of consideration and a much greater amount of talk. Organizations have been set up to promote the interests of manufacturers, and at one time there was a danger that they would overlap and that their number would divide the undoubtedly large forces at their back and fritter them away so that no effectua. action would be taken. Fortunately this danger has been apprehended, and there is a strong tendency to co-operation and federation with a unification of organization that must bring about a powerful body representing British trade.

In deliberating upon the action to be taken, every effort must be made to give due weight to each consideration and to avoid turning a principle eminently true and valuable into a shibboleth and pushing it to such an extent that, in place of being beneficial, it becomes mischievous. I believe the keynote of our success in the future to be co-operation and federation. Our motto should be that of the Belgians: "Each for all and all for each." Just as among our own engineering Institutions, as I have already argued, we should have correlation of all individual organizations, so in the world of industry we should have co-operation of all individual manufacturers and joint action. The same principle is capable of application on a still grander scale, and having already federation among our own Dominions may we not hope that our alliance with the other great branch of the Anglo-Saxon race may not be for the time of the war only, but that some way may be found, if not of actual federation, at all events of working together in harmony for the good of our branch of the human race and opposing those nations who have shown their whole nature, ideals, and methods to be antagonistic to our own, and of combating dangers of which the embryo is only faintly discerned at present but which in the fullness of time may threaten our very existence.

Preservation of Individualism.

Believing, as I do, most fully in this combination that I have advocated, I would indicate the dangers arising from making it into a shibboleth. While it is imperative that combination should be effected among manufacturers for the promotion of the Empire's world trade, in combining let us not forget it is the individualism of the Briton which has brought him into the position that he occupies in the world. I venture to think that too little appreciation has been evinced of this position. With all the castigation which British traders have received from the Press and public speakers for their want of method and for various other faults, need we be so very much ashamed of what this country has done in the past? Was our position such a very poor one when the war broke out? Did not our trade extend to the utmost ends of the earth and was not British probity respected in every corner of the globe? I would rather have the assets of the Briton than of the German in 1914,

but this is not to say that we cannot improve upon the position which we then held, and for this improvement undoubtedly combination is necessary. All I would urge is that this combination should be effected on lines which will recognize the British characteristic of individuality. Just as in warfare the individual German cannot be driven forward to fight unless he can feel another man's shoulder on each side of him, while the British soldier fights best in extended order, so the autocratic and machine-like methods of training suitable for the German cannot be successfully applied to the British manufacturer, who does best when he retains his own initiative and individuality. I am happy to believe that there is every indication that combination will be effected on lines which will not crush out the small manufacturer, and which will enable combinations of firms to be made in such a manner that the orders are obtained by a common organization while the work is carried out in individual factories, each factory taking that portion for which it is best suited.

Need for Supporting National Industry.

There is one danger to our trade which I greatly fear, and which will be realized unless we as individuals can rise above our own selfish immediate apparent interests and can consider the good of the nation as a whole.

The outbreak of war probably took all of us by surprise, but not the subsequent demonstration of the depths of degradation of the German mind and soul. To many of us the whole tendency of modern German thought and aspiration and the German methods of commerce were wholly and utterly repulsive, and many of us were fully alive to the danger to which this country was exposed by the insane encouragement given to the import of German manufactures and the fatuous belief in German superiority. The eyes of many have been opened, but whether the awakening is permanent time alone can show. Never was the warning "Lest we forget" more necessary than now. Let us remember that the leopard does not change his spots and, once the sheep's clothing has been stripped off, let us never again be deceived by the artificial exterior, however woolly and lamblike it may appear; the spots are still there. Let us not be deceived. The German has been our deadly enemy for many years past, he has been our open enemy during the last three years, and nothing has occurred which can render it in the least degree probable that he will become anything less of an enemy in the future. Let every man who is tempted, as he will be tempted, and tempted very strongly, in the near future to fall back into his old reliance on German produce remember that in yielding on account of what appears to him to be his immediate commercial advantage he is showing himself to be a traitor to his country, and is ultimately assisting in his own downfall. If this nation is to survive in the industrial war on which we must shortly enter, it can only do so by recognizing its enemies and by its individuals holding together and supporting each other's efforts for the common welfare. Let the first question asked when dealing with a firm be "Is it British?" and if it be not then let one be sought that is. It may be contended that in many branches of the industry the British-produced article is inferior to, as well as dearer than, the German. If we assume this to be true the obvious line of action is to take steps to improve the manufacture of that article and to give those who make it a market to supply; the British manufacturer will very soon rise to the occasion and rapidly pass his German competitor if only he be given the chance.

Capital for British Industry.

The war has powerfully affected capital and labour individually and their mutual relations. The expenditure on warlike material, in connection with much of which an immense amount of accumulated wealth produced by the industry of mankind has been absolutely and irrecoverably dissipated, coupled with a great reduction in the ratio of exports to imports, has impoverished the nation and driven large amounts of capital into other hands than ours. The result will be that many of the profitable enterprises presenting themselves after the war will have to be financed in large measure by foreign capital. This is a danger that must be watched closely, for it will greatly mar the value of the expansion of our trade if the profits go out of the country, and it will obviously retard progress seriously if they are not available for the nourishment of our own business.

There is, however, an encouraging feature in connection with the war's effect on capital, namely, the bringing home to most what was already known to many, that our industry was strangled for want of financial support, more especially in connection with new inventions which, while involving risks, contain also vast possibilities. We may hope that broader and wiser views will prevail in future and that British capital will to a much larger extent be applied to the development of British trade instead of being sent abroad to provide the sinews of war for the foreigner to attack our trade.

Labour.

It is in labour probably that the most tremendous problem of the immediate future resides. The effects of the war thereon have been manifold, far-reaching, and powerful.

The power and influence in the hands of the workman have been demonstrated in an unmistakable manner. From his ranks has been drawn a large proportion of the men forming our heroic navy and army, and without him the munitions necessary for the prosecution of the war could not have been forthcoming. We cannot shut our eyes to the fact that the events in Russia must show labour what can be effected by numbers, though it may be hoped that it may equally serve to bring home to the workman how disastrous to his nation and to himself as an individual the exercise of his power without proper guidance may be.

The stress of war and the necessity for increased production have cast a lurid light on the methods adopted by the workmen in their supposed interests

in times before the war. The Government has had to assume heavy responsibilities in overriding some of the most cherished rules of trade unions, such, for instance, as restriction of output and the non-interchangeability of different kinds of labour. Equally it has dragooned masters into acting as they were ordered instead of as they desired. The ultimate fruits of this action, necessary though it may have been to enable the situation to be dealt with, have yet to be reaped. When once the war is over, neither masters nor men are likely to put up with their relations with one another being interfered with by outside authorities even so exalted as the Government, and the fate of industry will depend upon how the acutely difficult problems are faced and dealt with by the two parties concerned.

Re-adjustment of Labour.

While masters and men have learnt much and perhaps have changed their views on many subjects, altogether new problems have been introduced by the war into a situation already bristling with difficulties. Many hold that the vast numbers of men hitherto following sedentary occupations, having once tasted an open-air life, will never return to their desks. While it may be permitted to doubt whether, on the contrary, they may not be only too thankful to return to their old lives, it is quite possible that the effect will be that indicated, in which event there will be a large access of new labour to the ranks of many branches of industry. Yet another readjustment may arise from the improved prospects of agriculture as a calling.

Women's Labour.

The extraordinary development of women's labour raises issues that are intricate and new. Having tasted independence and high wages, a number of those now working will desire to continue their present activities and probably this will be bitterly opposed by the men, but I do not believe that there will be any great access of women permanently to the ranks of engineering workers. While recognizing wholeheartedly the magnificent work that women have done in this sphere, I am convinced that the present state of things is entirely unnatural and a product of the unnatural conditions of warfare. The greatest incentive in the case of many women has been the feeling that their work was directly helping the men individually dear to them who were fighting to defend them and their sisters from the foul horrors of the German beast. This incentive will vanish with the war. Again women are physically unfit to endure the heavy work inseparable from most engineering operations; they may support it for a time, but, if persevered in, the results can hardly fail to be disastrous. The major part of the nation values home life and finds in it the centre around which their thoughts and activities revolve; there can be no home life if the women spend the bulk of their working hours in factories.

Future Position of Labour.

These new elements superimposed on the old in connection with labour problems render those problems more difficult of solution, but on the other hand the upheaval that has taken place has probably so affected men's minds that they will be able to approach the matter with far more hope of success than if their ideas had remained stereotyped. Superficially it would seem that much blame attaches to labour for strikes, attempts to evade the agreement not to restrict output, demands for higher and higher wages, and for many other acts. Before the war the attitude of labour to capital and the community at large on many occasions seemed unreasonable, rapacious and unpatriotic. Unquestionably mistakes have been made and the rank and file have often been misguided, sometimes by their recognized leaders, sometimes by those who have usurped leadership, but, little as we may like to admit it, there have been many reprehensible actions on the part of the employers and the men's attitude has not always been without strong provocation.

No one can listen to the speeches of some of the labour leaders and be acquainted with their personalities without recognizing the marked ability and honesty of purpose of many of them. Certainly all those who have had direct dealings with workmen themselves must acknowledge that as individuals many command respect for their general character as men and their ability as workmen. That there is serious unrest at present is certain, and much of it has been traced to causes that give reasonable grounds for its existence.

The question of labour is too vast and too complicated to enter into here, but it is quite certain that the men will have to be given a much greater share in the management and profits of the undertakings they are engaged on. It is equally certain that they are not at present fit to occupy the position that the importance of their contribution to the country's wealth justifies. They must be taught that they have duties as well as rights; they must be educated to take an intelligent interest in their work and in its development; their prejudices, ignorance, and suspicion must be broken down and many serious misconceptions cleared away. Masters must learn that they themselves must do what they enjoin on their men; they must remove their own ignorance of the conditions of life and of the viewpoint of their men, and they must get rid of the suspicion that they entertain of the men which is just as great and perhaps as ill-founded as the men's suspicion of them. While asking the men to deal fairly with them they must see to it that they set the example of fairness.

It will be said that all this is very true and very trite but how are all these fine sentiments to be put into practice? I can only say that they have got to be, and unless masters and men can succeed in understanding and trusting one another and in working together for the common good, this nation must go under in the industrial strife before us. The nation is but an aggregate of individuals, and unless each one works to the utmost of his capacity, giving his maximum out-

put in labour and ability, we must infallibly be beaten by those nations whose individuals will do this.

I believe success is to be attained by giving each man in some way or another a direct interest in the financial results of the concern employing him; by letting him have some say in its management; by treating him as a man and not as a machine; by letting individuality have play; by ensuring that every man even though not brilliant shall if he works steadily be decently housed, clothed, and fed; by shielding men from coercion by their fellows, tending to reduce their efficiency; and by promoting in every way mutual regard and trust between employers and employed. No doubt the attainment of these objects will radically alter the conditions to which we have grown accustomed, but in any case they will be changed and it is for this generation to see that they are ameliorated so far as the nation as a whole is concerned and not turned into chaos and ruin.

Education.

Perhaps the most potent influence in directing the imminent changes into the proper channel, as well as in assisting us in our competition with other nations, is education. In the past a large section of the British public has been obsessed in the most extraordinary fashion with the idea of German superiority in science and engineering. I deny this superiority *in toto*. I believe that British scientific men have been in the van of progress from the dawn of science, and that British engineers and manufacturers have led the way and have only been hampered by the unfair commercial methods of their rivals and by the mistakes that have been made by their own countrymen in regard to matters which cannot properly be touched upon in an address of this character.

We have been told many times that science and money provide the only ways of winning the war, and a strong agitation has been promoted to elevate science to a pinnacle and to make it the be-all and end-all of education and existence. Are we so very greatly impressed with the results upon the German nation of the cultivation of science to the exclusion of other human activities? Are we indeed proud of the part which science has played in this war? To my mind it is the most terrible degradation of what should be a beneficent field of human effort to see the results of so much patient, self-sacrificing, and earnest research devoted to the destruction of human life by the most horrible and revolting means, and to the infliction upon poor humanity of the most agonizing torture. I say that it will be many years before science can live down this disgrace and that no more powerful argument than this war could be adduced by the enemies of science in favour of those older methods of education which in some directions have no doubt been open to criticism. By all means let us continue in every way in our power the pursuit of scientific research and let us endeavour to imbue every human being with an appreciation of its importance and give to him a knowledge of the principles of science, but let us while giving to science the high position that is its due, keep it in its proper place and not imagine that it can be a substitute for those moral and religious principles which alone can afford adequate or worthy motives for human action or give courage to fight and persevere, and ultimately to conquer, in a righteous cause.

I was greatly struck to find the following words in a Government Report on Industrial Unrest in the North-Western area written by men of the world after careful, unimpassioned, judicial inquiry: "Undoubtedly the main causes of unrest, which no Government can allay, arise from human selfishness in all classes, a narrow outlook on the possibilities of co-operation, and forgetfulness of the golden rule to do unto others as you would be done by." Comment is unnecessary: science has no such golden rule, nay it scoffs at it, and the truths discovered during its mushroom life hold nothing of such importance to humanity as this eternal verity enunciated 2,000 years ago.

Education is one of the most vital questions that affect the life and progress of nations, and unfortunately it is one around which bitter controversy often rages and concerning which more mistakes have been made than perhaps any other. The very meaning of the word is often obscured, and training for a particular pursuit is confounded with the training of the character and the moulding of the individual into one who will advance the race in the struggle for improvement.

Engineering and scientific training are absolutely essential to an industrial nation, but it must never be forgotten that they provide only the tools which must be as perfect of their kind as they can be and without which no work can be done; it is the human, mental, and moral qualities of the nation which will decide the issue in the world competition.

Importance of Home Market.

Let us now turn to one or two matters affecting our internal affairs as distinguished from our foreign trade.

When the war is over, manufacturers will be faced with the need for reorganizing, for the production of articles of peaceful commerce, works modified, and in many instances largely created, for the manufacture of munitions of war, and this beating of the sword into the ploughshare will be fraught with very considerable difficulty. Opinions differ somewhat sharply as to what course will have to be followed; whether, for example, efforts will have to be made to find a use for the large numbers of special machine tools that have been made or whether the majority will have been so worn out by continuous use and unskilled handling that they are practically scrap material. If this latter view be correct, manufacturers should be allowed to write them off out of the money that would otherwise be regarded as excess profit. Whatever be the solution arrived at, it is clear that there will be facilities for production greatly in excess of those existing before the war, and every effort will have to be made to find markets of sufficient magnitude to absorb the output necessary for a profitable return on the capital invested. The capture of the foreign trade required will be greatly facilitated by the retention of the home market in British hands, and it is to be hoped that this will be realized in the proper quarters and that legislation will be on statesmanlike lines.

Power Supply.

Actual, not Ideal Position to be dealt with.

One of the most pressing and important home problems is the provision of a cheap supply, in adequate quantities, in all parts of the country, of electrical energy for motive power, for furnace work and electro-chemical industries, and for factory and other lighting. The matter has fortunately received the attention of the Government, and Committees with expert knowledge have been appointed to inquire into and advise on it. The members of this Institution are thoroughly familiar with the question and I need not do more than refer briefly to a few points in connection with it that are perhaps not quite generally recognized. It is obvious that if we were starting now with our present knowledge we should not provide electrical energy in such a comparatively small area as England or even Great Britain from hundreds of independent stations, many of them badly situated for the first essentials of economical generation, most of them having very small generating sets of obsolete and inefficient type, and supplying on systems differing from one another in every conceivable way. Clearly if we had to begin now, not only with our present knowledge and facilities but also, and let me emphasize this, with the present demand and state of public knowledge and opinion of electrical appliances, we should put down a relatively small number of large stations in positions chosen for their facilities for economical generation, all working on an identical system and suitably interconnected.

Existing Undertakings and Personnel.

But we are not starting now, and those of us who have been engaged in the business of electric supply from the earliest days—my own earliest experiences having been at the Grosvenor Gallery station before a shaft had turned round at Deptford—and who have been through all the stages that have led up to our present grasp of the problem, know full well how arduous has been the task and how heavy the cost of gaining the knowledge that is now the common possession of the industry. We cannot ignore what has gone before, and it is ungenerous and unreasonable to belittle what has been done in the past or to ridicule the existing stations which are the monuments of successful endeavour, and, if also of mistakes, of mistakes which have taught those who now know so much more than their predecessors. Any scheme which is brought forward cannot, in common justice, ignore the claims of those who are now carrying on the business which they have built up by their capital, by their work, and by their skill. Due provision must be made for the gradual wiping off of the existing capital, and adequate compensation must be given to those displaced whose lives have been devoted to what they had every right to expect would be a lifelong business.

Gradual Development.

The objects in view will best be attained by developing what is good in existing systems and eliminating what is bad, rather than by attempting to supersede all that has been done suddenly and abruptly. Although cataclysms occur in Nature they are usually destructive and not constructive. All natural organic growth is gradual and the same principle is well seen in the industrial world; most of the largest, and all of the healthiest, concerns have sprung up from small beginnings and have developed gradually into their present position. Instances in which attempts have been made to found concerns on a very large scale from the beginning will readily occur to you in which the financial results were for many years disappointing, if not disastrous.

There are a number of existing stations in which the generating units are large and well-nigh as efficient as any that can be devised at the present day and which are well situated for economical working. Let these be linked up to adjacent stations and let them be worked to their utmost, in some instances being extended, and let the smaller gradually be eliminated, the worst being shut down at once and the others worked in such a way as to contribute what they can efficiently to the general supply until the cost of their plant is wiped out. I would remind you that it may quite possibly be more economical to work inefficient plant already in existence to provide stand-by supply than to purchase new and more efficient plant for the purpose. Side by side with this development let new stations on ideal lines be erected to supplement the old, which in due course they will supplant.

To sum up what I have said we must again have co-operation and co-ordination of existing concerns. I am convinced that not only must justice be done and the problem of the old and the new be treated as a whole, due allowance being made for invested capital and for existing personnel, and that the most economical procedure will be to develop gradually, but I believe as a matter of policy the object we all desire will be soonest attained in this manner. However powerfully supported any new scheme may be, it cannot be denied that the vested interests in existence are very strong, and it must render progress much more rapid and tend to secure much earlier realization of ideal conditions if the opposition of such vested interests is disarmed and their assistance even obtained.

Economy of Fuel.

Combination of Gas and Electrical Engineers.

Closely connected with the problem of power supply is that of national economy of fuel. Partly from the bitter experience of war and partly, perhaps, from contact with our glorious ally France, one of the most economical of nations, we have begun to realize the necessity of not wasting our irreplaceable national asset. There is a tendency to confuse economy of fuel with cheap power supply, but the two are quite distinct though closely connected. I venture to think that, in regard to these matters, electrical engineers have been apt to arrogate to themselves too prominent a position. It is little short of ludicrous to ignore the great gas industry either in respect of their consumption of coal or of the experience of their engineers and managers. While for motive power and lighting and for certain kinds of furnace work, electrical operation is pre-

eminent and will almost certainly in the fullness of time be universal, there will still be an immense field for heating by gas. Apart from this, however, I hold most strongly that gas production will be an intermediary between the raw fuel and the live steam and so be concerned in the generation of the whole of the electrical energy used. I have for many years advocated the close co-operation, if not the fusion, of gas and electric interests, and I believe an appreciation of the soundness of this view is gaining ground.

It is to the national interest that the maximum useful result should be obtained in dealing with the fuel, even though the greatest amount of electrical energy may not be obtained from each pound of fuel that could be extracted. It would be folly to forgo the manufacture of those bye-products and their derivatives which give rise to whole industries, and it is here that the enterprise and skill of the chemist and of the gas engineer and manager come in. If each expert keeps to his own domain the greatest good to the nation will ensue. The whole of the coal raised should be treated as near the pit as practicable for the extraction of those substances usually referred to by the generic name of bye-products and for the production of a fuel, whether solid, liquid or gaseous, or one or more combined, which can be conveniently used for the direct production of steam. At this point the electrical engineer should take the matter in hand and produce his steam and conduct the other operations necessary to provide the electrical energy for transmission at high pressure to the distributing centres.

Line of Demarcation.

I do not think the proposal which has been made is sound to draw the dividing line later and let the gas works supply the steam. Electrical engineers have made the production and utilization of steam their own field and they are pre-eminently expert in it, while gas engineers have not been called upon to consider this problem to any great extent nor under the conditions imposed by a generating station. Moreover I think there would be practical operating objections to this line of demarcation.

Positions for Generating Stations.

In the new circumstances, it is obvious that the sites of generating stations will be determined in future solely by the facilities for carrying on the operations named and will be uninfluenced to any material extent by their proximity to centres of demand. The only way in which the interests of fuel-economy and efficient distribution can be reconciled is by the use of extremely high pressures of transmission and by other means for the reduction of the cost of mains ; even so, it may well be that the cheapest, as distinguished from the most efficient, supply of a given quantity of energy at a given point may not be realized, although on the whole the most economical use of the fuel will have been made.

Supply of Heat.

The problem of the production of heat in detail to supply a distributed demand for warming buildings and for cooking purposes will require careful study. The present crude methods are cheap, simple, and to a large extent convenient, and, so far as the heating effect is concerned, as distinguished from the effect on the atmosphere of towns, agreeable and wholesome, but they are criminally inefficient.

Electric cooking will probably be very largely used on account of its intrinsic merits ; improvements in cooking appliances have already been effected, and with increased demand we may look forward to robustly designed simple appliances that can be handled without damage by the ordinary domestic servant and that will be sold at prices comparable with those of the articles displaced. Electric heating of rooms will also have a large field in those cases in which convenience is an overwhelming consideration, such as in rooms used occasionally or for a few hours a day. I do not believe that electric heating will be employed for steady all-day heating or for boiling the large quantities of water required for domestic and trade purposes, because it will never be cheap or economical to do so. This heating will probably be done to a large extent in the smaller houses by gas or by some solid fuel produced in the gasification of coal. In large establishments, blocks of offices, factories and all large buildings some form of central heating in which the heat is produced by solid fuel of the kind I have indicated, or possibly by liquid fuel, will probably be introduced on the grounds of cheapness and economy though certainly not of comfort or health. If gas be used extensively for heating, new problems in its distribution will have to be faced eventually, arising from the concentration of gas production in centres often distant from the area to be supplied. For a long time to come, however, many existing gas works will continue to produce gas and bye-products and possibly where conditions are favourable to steam operation contribute their quota to the electric supply, just as will continue to be done by stations run by blast furnace gas.

Electrical Distribution.

Our practice in distribution is undergoing development in consequence of the increase in the amount of power to be conveyed. Large motors are now run at high pressure and in some measure there is a reversion to the old system of house transformers on a greatly magnified scale. I do not see how it will ever be possible to deal with general distribution to very small consumers except by the use of low pressure networks, and in all probability there will be a double system of high and low pressure distribution, large consumers of power whether for motive power, heating, furnace or electro-chemical work being connected to the high, and domestic and shop requirements being provided from the low.

The developments in store promise to be of the greatest interest and will bring back the earlier days of electric supply when new problems, which had to be met one way or the other, were arising every day, and they will lift central station work out of the dull routine into which it seemed likely to settle down.

Electrical Engineers.

Consultants.

There is a tendency at the present time to regard manufacturing as synonymous with electrical engineering and to disregard the other branches of the latter, more especially to belittle the consulting engineer, many going so far as to say that he will shortly disappear. While recognizing to the full the importance of the position of manufacturers and the shortcomings of many of those calling themselves consultants, I think it would be a distinct loss to the profession were the consulting engineer to be eliminated and his work taken over by the manufacturer. The lopping off of a branch corresponding to the highest positions in civil engineering and in other professions, such as the medical, would be greatly to be deplored, as it would mean the narrowing down of a profession which now embraces every branch of an engineer's work. Apart from this, there would be a distinct loss to the industry. From the manufacturer's point of view, it is clearly advantageous to have someone who can state the purchaser's requirements in a definite manner in terms that can be understood without ambiguity, so that all tenders are on an equal footing, and who is able to appreciate the relative values of the offers firms make irrespective of the persuasive powers of their representatives. From the purchaser's standpoint, the consultant necessarily takes a broader view, and his advice is likely to be more reliable, than that of any individual firm of manufacturers who, however honest in intention, must necessarily be biased in favour of their own methods of attacking a problem and who will be tied largely to their own designs which may not be uniformly the best. In my experience, also, the consultant is often able materially to assist manufacturers by putting before them the needs of users that they would never have thought of, and by defining precisely the conditions to be fulfilled in a manner that the user never could on account of his not possessing the necessary technical knowledge to enable him to do so.

Etiquette.

I venture to think that all parties would benefit by a stricter etiquette than now exists. Manufacturers should support the consultant in the same way that the general practitioner does the Harley-street specialist or the solicitor the King's Counsel, instead of providing advice gratis and ousting the consultant. On the other hand, the consultant (as all the leading men do) should confine himself strictly to occupying an advisory position without interest, however remote, in any manufacturing concern and abstain from indulging in his own fads, a practice that has greatly irritated manufacturers and contributed largely to the present situation.

Managers.

A reform greatly needed in connection with engineering concerns is the appointment of men of high technical qualifications instead of clerks to position of manager or secretary. It is monstrous that engineers should undergo a lengthy and arduous training, provide the skill, inventiveness, and high qualities necessary for the efficient management of men, to find themselves in receipt of rewards only a fraction of those bestowed on an individual whose attainments are purely clerical and who has it in his power to mar their efforts and to whom they must to a large extent be subservient. It is absurd to argue that the engineer often has no business capacity; if he has any real claim to be called an engineer he must possess commercial ability, for it is this very attribute which distinguishes him from the man of pure science; he has got to make his designs pay. There is no training so calculated to cultivate the intellect and to broaden a man's outlook as engineering, and an engineer will grasp business problems infinitely better than a clerk. An engineering undertaking should be managed by an engineer; engineers have the power to ensure this entirely in their own hands; they are absolutely indispensable and if properly organized can secure their proper position in commercial undertakings.

Engineers and the Public.

It is a matter for surprise that engineers should count for so little in the public eye. The man in the street knows little, usually not even the names, of our most famous engineers, while singers of senseless songs, vulgar buffoons, food faddists, cranks, authors of nasty or silly novels, and the propounders of grotesque views on religious matters, are with him household words. Politicians also of every kind occupy a prominent place in his admiration. Why is this? Largely, no doubt, because the average intellectual level in any country is low and any individual whose mind is above it can make no appeal to the average man, while the popular heroes more often appeal to the passions common to all mankind rather than to the mind the quality of which varies so much. Partly, however, engineers themselves are to blame. They have, as I have said, let others occupy the prominent positions that are theirs by right, those positions which bring them most into contact with their non-engineering fellow-men, and have perhaps been apt to look with contempt on popular appreciation and on the shifts of notoriety seekers. We are often told that this is an engineer's war—a doubtful compliment—but unquestionably the public has had brought home to it the resourcefulness and widespread power of the engineer and a large number of people have acquired a smattering of engineering which, however small, must tend to increase respect for our profession. The time, therefore, seems ripe for a change.

Organization for War.

There is no reason to suppose that engineering will become of less importance in warfare, nor, alas, that warfare will cease to have to be provided for. We ought, therefore, to start and maintain an organization that shall ensure that the technically trained material in the country shall be applied with maximum effect immediately war breaks out, and avoid the lamentable waste that has occurred in the present war by disregarding the technical qualifications of many and by giving others technical work for which their training

has been unsuited. Not only should all individual engineers be classified according to a well thought-out scheme, but actual posts in a war organization should be assigned to them. I would regard each technical Government staff as a sort of nucleus crew and make definite appointments to come into force on the outbreak of war, with adequate reserves to draw upon, so that every staff could expand automatically when the stress of extra work came on it, and I would give these reserve men an insight into official methods so that their technical knowledge might be instantly utilizable. In some cases, whole departments would have to be created in war time with no nucleus crews : here again I would have a definite personnel ready. There would, of course, be a gradual change of men during peace as time went by, so that the organization might be kept up to date and men in the prime of life and of proved attainments be ready at the nation's call. Similarly all factories should be organized so that each would in war time contribute a definite product in definite quantities when the war need arose.

Engineering Students.

I fear I have already tried your patience far beyond its elastic limit and I will now conclude with a few words to the youngest members of the Institution, to those who are in the stage of students and who are just entering the world of engineering. From these will be drawn future Presidents and Councils, and on them will devolve the duty of preserving traditions that are good and of improving on the work of their predecessors. Let them take full advantage of the facilities offered them by attending the Ordinary Meetings and listening to discussions on the pressing problems of the day ; the spoken word can never be replaced fully by the written report, and often they will find themselves going home with some new thought or inspiration, arising perhaps from some chance remark of a speaker, that may lead to results of the utmost importance. More especially would I urge them to attend the Students' Meetings. I know of nothing more conducive to clear thinking than the writing of a paper, and joining in discussions is a splendid training ; it promotes celerity of thought and readiness of speech and the experience gained will be found invaluable in after years. Attendance at meetings is useful also in making a man known to his contemporaries and in familiarizing him with those ahead of him. Although I believe they will derive these great benefits from joining the Institution, let not this be their first thought, rather let each ask himself what he can give to the Institution and to the industry at large.

Engineering as a Profession.

A word as to engineering as a profession ; it surely, rightly apprehended, is one of the most ennobling. It requires an active brain, making, as it does, a direct appeal to the intellect, and it brings a man into intimate contact with the laws and processes of Nature and their everlasting truths, while constructive work is the nearest approach to creation possible to a created being. Contact with Nature at first hand and the consequent realization of the puniness of man, as well as of his infinite possibilities, must surely engender a spirit of reverence and broaden the mind in a manner few vocations can. It is a boon of priceless value for a man to find himself in daily contact with men of sense and knowledge, and as he progresses in his profession to have for his companions and intimate friends those who are in the forefront of thought and discovery and also are among the brightest intellects of his day ; it may tend to humility, but it will certainly sharpen his wits and make life better worth living.

I would particularly impress on the young engineer the need for thoroughness in all he does—" Whatsoever thy hand findeth to do, do it with thy might " is a maxim applying with peculiar force to engineering. Every piece of work carries with it three potentialities or values. The first is its money-getting capacity ; at this many stop ; they may become the richest in their profession but they will not be its leaders. The second is the possibility of an enduring monument of the engineer ; this is far greater than the first and of vastly more value to him as a man, and it will help him forward in his profession. Lastly there is the training in experience and in character, and this is the most valuable of all.

Strive after perfection and do not regard the smallest job as unworthy of your best efforts. Always say to yourself : This work that I am doing will remain perhaps long after I have disappeared—let there be nothing in it of which I need be ashamed hereafter ; let it be impossible to find in it in later years any sign of scamping or subterfuge. Let love of your work for the work's sake be your dominant motive and do not aim lower than perfection even though absolute perfection may be unobtainable ; believe me the more material benefits will be added to you.

DUBLIN LOCAL SECTION: CHAIRMAN'S ADDRESS,

By Captain O. T. O'Kelly Webber, R.E., Member.

(Address delivered 12 October, 1917.)

In the early days of the war this Local Section decided to suspend its meetings until the conditions were again normal, but notwithstanding that the war is still with us we are assembled once again in full session. I think that the members have every cause to congratulate themselves both on the vitality of the Section and on the vigour of its younger members, signs which are full of promise for the future when the normal course of progress is restored.

Although the Section has been nominally dormant, its Committee has been active in urging on the Government departments engaged in research work the investigation and development of the resources of this country for the production of power.

A Joint Engineering Committee on Peat was formed at the invitation of the Committee of this Local Section, in conjunction with the Institution of Civil Engineers of Ireland and the Engineering and Scientific Association. As a result, the investigation has been taken up by the Department of Scientific and Industrial Research, and if the terms of reference given to the Committee of Inquiry appointed by them are not so wide as we might wish, still it is an excellent beginning.

At the invitation of the Irish Committee of Inquiry, the Joint Committee has drawn up a report and Mr. Tomlinson has been nominated to give evidence on the matter of the report.

The Committee of the Local Section has also been in communication with the Electric Power Supply Committee of the Board of Trade. It has also urged upon the Board of Trade the investigation of the water power resources of Ireland. For this purpose a complete hydrographic survey of Ireland is a prime necessity. Nothing of the kind exists at present, only fragmentary surveys in connection with such schemes as the Shannon, the Erne, and the Bann, or reports in possession of the Board of Works such as Colonel Vallancy's survey of the canals and navigable rivers, and Sir William Willcocks' project for the drainage of the Barrow.

The Shannon was brought into prominence by Lord Northcliffe not long ago. Having the largest catchment area of any river in Ireland, it seems at first sight to offer the most promising field for development. Unfortunately, however, the great seasonal variation in the flow of the river has caused engineers to fight shy of any schemes connected with it. This defect seems to be irremediable because the basin of the river is so shallow that the superficial area of the water exposed to evaporation is altogether abnormal, and practically the entire summer flow is absorbed by evaporation before the water reaches the weir at Killaloe. It is my belief, however, that when this seasonal variation is not so exaggerated, the problem can be successfully attacked, for it is generally overlooked that those old mills, whose ruins we see distributed along our river banks, were only worked seasonally, yet they provided much employment and were remunerative to their owners in the days when wheat was grown profitably in Ireland. Moreover, the greatest industry in Ireland at the present time, that of agriculture, is itself a seasonal occupation, and in it there is to be found an undeveloped field of unproved extent for the utilization and application of power. The bogey that hinders the development of our water powers possesses no terrors for the farmer.

Let us consider the position of agriculture in the general perspective of all mechanical progress. In the first stage we see man producing by the power of his own labour, exercised through crude weapons and tools, barely enough to supply his own daily needs. In the second stage we see the power of domesticated animals, guided by human skill and intelligence, produce a surplus over the daily needs. And in the last stage we see mechanical energy, exercised through suitable machines, producing a surplus to which no man can now set a limit. Agriculture we see is in a transitional state extending over all three stages, but mainly over the first two and only utilizing mechanical energy when it has been compelled by the scale of operations to do so.

Thus many estates already possess a power plant of a kind, but it is generally in such an inelastic form as not to be adaptable to day-to-day uses, and where utilized for the production of electrical energy the energy is mainly or entirely devoted to lighting. In electrical energy, however, we have a medium available which is infinitely adaptable, and as an illuminant merely will be regarded in the future as a luxury product or by-product.

Now consider the possible applications of electrical energy to farming operations, and it will be convenient to group these under three heads, viz.—

(1) The minor day-to-day operations usually performed by manual labour.
(2) The larger operations usually performed by animal power or mechanical power.
(3) The development of novel and highly specialized applications.

Under (1) I include such operations as crushing fattening cake, slicing turnips and mangolds, cutting chaff, cleaning seed corn, pumping water, churning, and butter working machinery. The machines used

for these purposes absorb a great deal of manual labour, as they usually require a man and a boy or two men, one to work the machine and the other to feed it. All can be easily motor operated, and besides liberating week-day labour for more skilled employment, much Sunday work would be saved.

(2) Among these we have such applications as threshing, ploughing, and so on. I see difficulties in the application of electricity to ploughing, for instance, but does anyone suppose that when a supply is available those difficulties cannot be overcome? There are also such operations as sawing and working timber generally, and crushing stone for road metal incidental to farming on any scale. Probably the horse can never be dispensed with entirely as a producer of manure, and so its energy will always be a valuable by-product.

(3) In the third category of highly specialized applications I include such developments as electroculture, at present in the experimental stage.

There is also much scope for ingenuity in devices designed to cheat the climate, to enable the farmer to save his crops to better advantage, and to save waste and unnecessary handling.

The problems that I have presented have already attracted attention in the United States where hydraulic power engineers, witnessing the growing employment of internal-combustion tractors by New England farmers, have pointed to the undeveloped water powers in the same district and are working out the problems of generating electricity from them and delivering the energy to the farmers in a more adaptable form and at a less cost than it is possible to do by means of the farm tractor.

In the course of these remarks I have referred to two of the sources of power in Ireland, sources in the development of which the members of this Institution have by their actions already shown themselves to be deeply interested, and I have also attempted to arouse interest in a practically virgin market for our product waiting ready at our doors, one which should be doubly interesting to-day by reason of the importance of food production.

Unfortunately the need is too urgent for these methods to have an immediate practical application to food production, but there are in Ireland 10,000 holdings of 200 acres and upwards which must contain many potential consumers. Sceptics will say "Oh! the farmers are no good," and will hesitate at the difficulties of distribution. To the first I say that it is up to him to educate the farmer; and to the second, that modest beginnings sometimes develop into great undertakings, and that the imagination which is capable of conceiving a system of great power stations for the conversion of peat is not going to recoil from any difficulty of distribution.

YORKSHIRE LOCAL SECTION: CHAIRMAN'S ADDRESS.

By W. Lang, Member.

(Address delivered 7 November, 1917.)

It is fitting to refer, first of all, to those of our number who have been and are still serving in the various branches of H.M. Forces, and I feel sure you join wholeheartedly with me in offering our tribute to those who have fallen.

It is gratifying to know that our Institution is taking an active part in the effort to fit and assist those men, broken in the war, who are returning to civil life, and it is an opportunity that we all gladly welcome for every member to show in a practical way his appreciation and sympathy for anyone handicapped through his work in the fighting line.

The Work of a Local Section.

The Chairman in his Address has an opportunity of expressing his views in a somewhat informal way, but while he has this freedom there is a corresponding limitation upon him to avoid debatable questions, as it has become customary and is unusual to have any discussion on such an address. Customs die hard, but I feel that the Local Section and the Institution as a body would benefit if it could be arranged to fill in what we might term the hiatus which exists between the ordinary meeting at which a paper on a specific subject is dealt with and discussed and the Chairman's Address dealing with the position and work of our Institution, which is accepted without any debate. If it were possible to devise a means whereby the ordinary member could express his views in an informal way on the work of the Local Section, it would be an incentive to each member to take a keener interest in his membership. It must be admitted that the majority of members are passive rather than active in their membership, and it would be a somewhat instructive confession meeting were members to give their reasons for joining the Institution.

One of the difficulties in the path of change lies, I think, in the very ideals of our Institution and in the possibility of endangering the very exalted position which our Institution undoubtedly holds in the esteem and respect of all scientific and technical bodies throughout the Empire. It would be a grave matter to depart from the precedent which has secured this prominence. From its inception and throughout its career it has fostered the highest conception of the value of high standards for our industry and all who are engaged in it. The industry owes no small debt of gratitude to the Institution for its work in this direction, but it is always profitable to inquire whether ideals which were correct at the inception are sufficiently high to serve for all time in any Institution. If we assume, for example, an Institution having only mental ideals and neglecting entirely the physical needs of its members, we need hardly be surprised at lack of energy or activity unless it confine itself to a very limited number of enthusiasts.

Our Institution, however, has gone forward very rapidly increasing its membership, and I feel sure it would be filling its highest ideal in existing for the industry in all its needs rather than the industry existing to enthrone its Institution on a pedestal apart.

It is safe to assert that there are comparatively few members of the Institution who do not earn their living in their vocation as electrical engineers, and yet little consideration is given by the Institution to what we may term the more personal needs of the members themselves. Possibly if we had opportunities of discussing members' personal needs and difficulties, and, instead of having the vast majority of our members inarticulate, we had their views say once every session on such questions as "the past year's work of the Institution or Local Section"; "the value of membership"; or "the welfare of our members," we might be able to meet the needs as an Institution of the physical wants of our members as well as to supply them with mental nourishment.

One departure of note during the past session is the adoption of voting by proxy—a movement initiated by the Manchester Local Section—which gives every member an opportunity of expressing his opinion in his vote on any matter to be decided upon in this way. This gives the ordinary member in the Provinces an interest and a voice in any important changes and will undoubtedly have great influence on future development of our Institution.

Commercial Engineering.

The progress and development of our industry is the subject which occupies our minds at the beginning of every session, and possibly no period has been fraught with difficulties comparable with the times we now experience.

The major problems are meantime outwith the scope of discussion, but in whatever way concentration and effort are directed in the future, there is one field of activity which will remain a constant factor in all our development. To this factor I propose to refer under the title of "Commercial Engineering." It is this factor which involves the work of securing new business and which is familiar to us as "the problem of the new consumer."

No one will disagree with the claim that the subject is of vital importance; and this is accentuated when it is remembered that, however well devised may be any schemes of organization for mutual support and economy within the industry itself, these schemes will always

require the same effort by the industry to exploit its attractions and advantages to potential users. The subject has always been worthy of greater attention than has been given to it; it is especially opportune at the present time when the industry is in a state of flux, and in itself it is deserving of a degree of official recognition which has been denied to it in the past but which it will, I feel sure, demand in the future.

It would simplify matters considerably if it were possible to define the place and mark the sphere in which commercial engineering is exercised, but this is hardly possible until our recognition of its importance and experience in its operation has been very considerably developed. Further, in any consideration of the question of the commercial work involved in our industry, it is advisable to bear in mind that the majority of us have been trained as engineers and not as "commercial" or purely business men, and it is to be expected that our opinions will show evidence of "engineering" or, one might say, "mechanical" bias.

This might be called a misfortune of an engineering training, if it could be termed misfortune, as we become attached to the mechanical side and somewhat one-sided in our outlook on life and business. We become accustomed to the known quantity in machinery; we never find it illogical, or unreasonable, or ungrateful; we can always tell when a weakness is developing and take measures accordingly, but we forget that after all it is only machinery, and that unless we mix with people, study all their emotions and get to know them, we cannot hope to have that mental poise necessary for dealing with problems of business.

It is more charitable to ourselves to say that engineers have been absorbed and engrossed by the "mechanical" interest in engineering to the neglect of its "business" requirements, than to say we have ignored and looked askance at anything so ordinary as commercialism; but there is justification for saying that engineers have considered themselves superior to what we know as "commercial travelling" and have endeavoured to carry on business as "engineers" and not as "business" men.

This appears to be confirmed by the very endeavours made in our industry to find a term with which to describe the commercial activities in which they engaged. The well-known terms "traveller" and "salesman," indicating work and duties which are obvious from the titles themselves, were found to be not quite appropriate, or perhaps inadequate, or possibly not quite euphonious, to those engaged in engineering work, and so the term "representative" was applied. There was some justification for this so long as it indicated to a client certain abilities to deal with problems of a technical nature, as well as the obvious fact that a commercial transaction was the object of the representative's call. On the other hand, however, it was in itself evidence of a poverty of talent in this work when it was found necessary by the industry to specially designate its trained men engaged on sales work.

In this it is possible to find one reason why the position has become very limited, carries little or no authority, and is held, very unjustly I think, in rather low esteem. There is no doubt we should be much better appreciated by the ordinary user were we to revert to the older term of "salesman" or "traveller" and see to it that only those men able to deal with electrical engineering problems were our salesmen.

The work entailed is not of recent growth, but was one of the hardest problems which the pioneers of our industry had to contend with at its inception. Their great difficulties were not so much the technical as the commercial problem of "where to find and how to secure consumers," and it must be admitted that, if we eliminate war conditions, this same problem is still giving our industry as much concern to-day as ever it did in the past.

Every industry owes much to its pioneers, and I have no hesitation in saying that our industry, as an engineering industry, has been fortunate in having had pioneers possessed of commercial aptitude upon which their success very largely depended. These pioneers might be designated our first commercial engineers, and yet I doubt whether they would feel flattered in being so described; in fact I am not quite sure whether the chiefs of our undertakings to-day would feel complimented if their office were associated with commercialism.

Whether or not this be so, it will at least be admitted that the successful issue of the year's business—and any future expansion of an undertaking—is not a mere matter of chance or "natural development," which is what we look for. The chances of failure or non-success are reduced to a minimum when a definite policy is adopted to ensure the retention of existing and the securing of new consumers—activities which are purely commercial and altogether apart from the procedure required for generation and supply, or as we might say, manufacture and delivery of the goods.

Now as a corrective to our views comes the entirely opposite opinion, that no special effort on commercial lines is necessary for the development of our industry. I confess it came as a complete surprise to me that anyone should hold this view, but I took advantage of several opportunities to interview engineers whose opinions would always be worthy of consideration, and it is undoubtedly the case that this view is held by some. In some cases it was qualified by the addition "for a long time to come."

This is really a matter of interest even if it is of surprise, and one is tempted to place this assumption to the credit of the demands which war conditions have put upon our industry, rather than to the ascendancy of our industry to that eminence which we desire it to hold. It is willingly admitted that war conditions have accelerated the normal rate of expansion to such an extent that it could be dealt with under war conditions only with difficulty, and even that much new business has been postponed if not refused altogether. Even when we admit this, and were we willing to convince ourselves that the pre-eminence of electricity supply is an accomplished and accepted fact, that our industry could adopt a waiting policy, and that it is unnecessary to press forward in the active work of securing "the new consumer," it would not be an attitude towards life and work which would long satisfy the majority of those who are engaged in our industry. It is difficult to account for this mental outlook on the future, as it is in such decided opposition

to all training on business lines, and is perhaps explained by the weakness of our training along purely engineering lines, to which I have already referred. It would be quite safe to say that no business undertaking of any size or of any kind in this country would rest content with an estimated "natural growth" without making definite arrangements to ensure its accomplishment, otherwise it would be an evidence that the mental capacity of the management was unable to keep pace with the possibilities within grasp and the proper expansion of the business.

There is a still further serious outlook in the fact that our undertakings have been steadily growing into, and have the prospect of becoming, vast business concerns rather than isolated supply centres, in the control and development of which the purely "mechanical" mind will be severely handicapped and in which other talents and wider experience of business will be absolutely essential.

It is greatly to the credit of an engineer when he is called upon to fill the position of chief of an undertaking that, although trained for the most part as an engineer, he acquires that business ability which is necessary for the direction of a large business undertaking, in many of the departments of which he has had little or no experience. It is not to our credit, however, that the training of men who will be the industry's future chiefs consists of a preponderatingly engineering tendency, when the industry itself will demand a wide commercial experience for its successful development. So long as concentration is mainly directed to the mechanical side of our industry, it will be inevitable that the industry's chiefs will be "engineers" in thought and wish and "business" men only by compulsion.

It would be a misrepresentation of fact if it were asserted that our industry had suffered unduly because of this; but the mental attitude which is that of "necessity" or "compulsion" towards the commercial engineering aspect is wrong, and it is to be feared that our engineers themselves, as well as the industry, will be the losers from the very intensity with which they have concentrated on the mechanical and electrical departments of the work. One might almost forecast a future condition of our industry where the chief engineer, as such, would apply only to the control of the practical side of our industry, and that at the head of the undertaking there would be an administrator not necessarily trained only and entirely as an engineer, but possessing engineering, financial, and commercial experience.

The very fact that in the past the chief engineer has been compelled to study ways and means to extend the supply for which he is responsible, to approach users of power and to exploit the attractions and advantages of electrical methods, is evidence in itself of the necessity for such work, and the heritage we enjoy to-day is the result of those early efforts.

It is usual to-day for the chief engineer to deal with important prospective business or selected inquiries and for routine work to be undertaken by canvassers. It is therefore somewhat of a paradox to practice commercially, to admit its necessity, and yet take no steps to organize the work on thoroughly commercial engineering lines. The whole trend of the industry is to give prominence to the electrical and mechanical side of the business and to trust to some "chance" or "instinct" to deal successfully with commercial engineering needs.

To devote the whole talents of the undertaking to the engineering side is to say in effect that absolutely reliable service is the only ground on which the industry can progress; for this resolves itself into the assertion: "Here is the supply; it is perfect and meets every need; there are the terms—take or leave them."

It will be agreed at once that this would be an entirely wrong construction to put upon the attitude of our industry to the consumer, and possibly no business has recognized so quickly as our industry that low costs and low charges ensure success; but it is a mistake, commercially, to think that cheapness in itself, even for the most valuable product, will ensure success.

The proprietor of a valuable proprietary commodity does not wait until it gradually is passed on by one user to another. The most widely known of our household requisites is handled "commercially" to-day even when it might be assumed that every user knows of it. Whatever measure of success was obtained by "natural growth" would be no criterion of the success following upon good commercial handling, for it is a truism that it is possible for the best-made article to be "badly sold" and endanger the ultimate results of the most careful works costs. It is an accepted root principle that wherever anything manufactured is for sale, the paramount duty of those entrusted with its success is to study commercial methods, and to a very great extent the giving of public service makes the same demands on electrical engineers.

At this point it would be possible to conclude, as my endeavour has been to establish, at the least, the principle of and the necessity for an official recognition of commercial engineering training. Until this is accepted by our industry in a collective sense it will be of little advantage to enter into the debatable domain of ways and means for attaining the desired end; but to remove any misconception which may be engendered on the subject, it should be borne in mind that while commercial methods obtaining in ordinary business concerns might be taken generally as the basis, yet a very clear distinction can be drawn between these methods and those which would be likely to command success in our industry.

This distinction does not appear to have been realized, or at any rate recognized, otherwise the existing attempt would not have been persevered in. The most important distinction is that the work involved in securing new business for our industry is not confined simply to that sphere of operations comprised within what we term "salesmanship," as this term refers to specific work which is well defined, and it is incorrect to associate "salesmanship" in this sense with the giving of a public service.

A "salesman" has a personal interest in his client as he naturally hopes to increase his "sales" and his business, as time goes on, in which he will have a personal advantage. To promote a sale, or, as it should be put, "to secure a new consumer," in our industry

terminates the "salesman's" interest in that client, as the consumer then becomes part of the system and the necessity of keeping in touch with him is not so essential as in the presence of competitors for ordinary business transactions.

For this reason it is unwise to look for or to expect from a canvasser of an electrical undertaking that keenness and interest which the ordinary commercial traveller develops, for the work of a commercial traveller has a cumulative effect which is entirely absent in our case. For the same reason the post will never attract men of outstanding commercial ability as there is no future to it. Nevertheless there are quite special conditions binding our undertakings to consumers which are peculiar to our industry alone.

The supply is never given "from stock," and yet what we might term the manufacture, despatch, delivery and satisfaction of the customer is immediate and instantaneous as between employee and the consumer. It might therefore be reasonable to expect that every employee engaged in an undertaking would have a direct incentive to study the point of view of the buyer he is serving and to learn the best methods of "disposing of his produce on the market." I do not mean to imply that every employee has an opportunity of doing the work of coming into personal contact with a consumer, but unless this spirit of "supplying a need" or "selling" is engendered in an undertaking, the employees become mere hewers of wood and drawers of water—they fulfil the task of raising steam or tending a switchboard without inspiration.

The difficulties surrounding the problem of "the new consumer" lie much nearer to our own doors than will be willingly admitted; they are to be found in the absence of any serious attempt to impart to employees, and especially to the juniors, the wider view of what is the ultimate and real object of all undertakings in our industry. It would be an incentive to employees if they knew what relation the costs of their part in the work bore to the final cost at the switchboard, and I feel sure it would give increased interest to every employee if he realized that his whole watch had an element of competition with preceding and succeeding watches on duty. The failure to realize that electrical supply comprises more than the study of the electrical and mechanical problems involved in giving continuity of supply to consumers, will possibly account for the fact that the majority of employees are content to consider their immediate duties and responsibilities complete in themselves, without an understanding of their influence on the ultimate object of the undertaking as a whole, or the relation between the costs of their particular work and the final charge to the consumer.

A very decided advance will have been made towards solving "the problem of the new consumer" when everyone engaged in the industry realizes that his training is incomplete without a certain amount of active commercial engineering experience.

NEWCASTLE LOCAL SECTION: CHAIRMAN'S ADDRESS.

By A. H. W. Marshall, Member.

(*Address delivered 12 November, 1917.*)

I purpose to take for the subject of this Address the use of electricity and its bearing on fuel-saving in the iron and steel trades, and I do so because it seems to me that it is to these trades the electrical industry will be associated for its greatest development in the immediate future. The war has given a great impetus to steel production, and in the period immediately after the war there seems to be every probability that the steel trade will continue to flourish provided that the cost of production is low enough to meet the intense competition which will then arise. The burden of taxes after the war will be heavily felt in consequence of our huge indebtedness and the maintenance of our food supply and, as wages will no doubt continue high, other costs will of necessity have to be kept as low as possible, which can only be done effectually by increasing the size of the undertakings and making use of the most efficient technical methods.

Up to quite recent times the mining of coal and ore, coking, smelting, steel-making and rolling have all been more or less separate undertakings, carried on with only so much co-operation as regards extent of output and location as was forced upon the firms engaged in each branch by their competition one with the other, and in which the expenditure of capital of any one part bore no fixed relation to the wants of the whole. That a change is now taking place is to be gathered from a statement made by Dr. Addison, then Minister of Munitions, in the House of Commons last June. He said:—

> "Should the war last we ought to find ourselves next year with a capacity for steel production more than 50 per cent greater than it was before the war with modern coke ovens equipped with recovery plants, with knowledge of how to extract the valuable by-products and with groups of blast furnaces, steel furnaces, and rolling mills arranged on a big scale suitably situated and co-ordinated with each other."

There is every indication that the next few years will see a greater combination of interests, better application of capital, and the utilization of every means to economy. This must result in the extended employment of electricity, as only by its use can full advantage be taken of the many economies to be effected in the energy account and the costs of power be reduced to a minimum.

With efficient plant and means for the recovery of surplus heat, it is commercially possible to meet all the heat and power requirements of a works that is laid out complete with coke ovens, blast furnaces, steel furnaces, and mills from the combustion of the coal fed into the coke ovens; that is to say, without burning any coal in producers for the steel furnaces or in boilers for any portion of the power plant. This is an ideal arrangement which has been aimed at by iron and steel manufacturers for some years but has not been attained, because even the largest undertakings although they can be made self-complete under normal operating conditions, have not been able either to dispense safely with their coal-fired heating plant, or to justify the capital expenditure necessary to make full use of their waste energy, owing to the many unavoidable irregularities to which the working of the coke ovens and furnaces are subject, and the dependence of one part of the works upon another. That such an economical arrangement can, however, be attained is evident if one applies the advantages of linking up to the electrical end, supposing, as is the case in this district, there is a large public power system which can be drawn upon or fed into as required.

I will try and show how the matter works out, as I think it is one that is perhaps not fully appreciated by electrical engineers, who have been given the idea that there are enormous quantities of gas and waste heat which could be converted into electrical energy and used for outside power purposes. This is not so, but the misunderstanding has come about because, as I have said, the several processes have been carried on independently of each other and the coal used on the producer and rolling-mill plant has been erroneously considered to be part of the fundamental requirements of iron and steel manufacture. It is only by taking full advantage of every means available for heat recovery that there is any margin of power to spare in a properly co-ordinated undertaking, excepting at week-ends and other times when, as now happens, the steel-works end of the plant is shut down. This is especially the case where electric furnaces are in use.

I propose to give a few figures to show how the energy of the coal, as fed to the coke ovens, is distributed in the processes of coking, smelting, and steel making.

In Table 1 and in the diagram the heat available at each stage is expressed in terms of one ton of coal carbonized, and the products are those which correspond therewith. The energy values are given in kilowatt-hours or kelvins, the latter being the better term, seeing that both heat and electricity are being measured. I am dealing with the conditions of iron and steel manufacture on the North-East Coast and have taken as a basis one ton of ordinary Durham coking coal having a value of 12,500 therms per pound.

TABLE I.

Distribution of Energy in 1 Ton of Coal (12,500 therms) containing 8,200 kelvins.

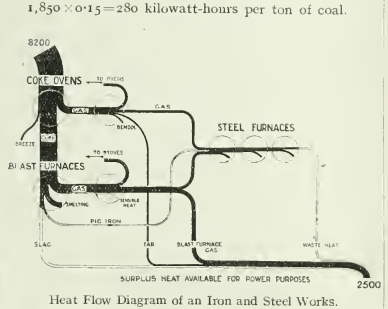
Quantity of Product		Kelvins	Kelvins available for Conversion to Power
	Carbonizing 1 Ton of Coal.		
5,500 cub. ft.	Gas used on ovens	690	—
5,000 ,,	Gas surplus ..	630	—
0·7 ton	Coke	0,000	—
0·05 ton	Coke breeze ..	300	—
100 lb.	Tar	470	350
2½ galls.	Benzol	110	—
		8,200	
	Smelting 0·64 Ton of Pig Iron.		
31,700 cub. ft.	Gas used on stoves	930	—
73,800 ,,	Gas surplus ..	2,160	—
1 ton	Slag (sensible heat)	650	650
0·64 ton	Pig iron ,,	250	—
	Furnace reactions and loss ..	2,010	—
		6,000	
	Utilization of Surplus Gas from Coke Ovens and Blast Furnaces.		
	Making steel (0·68 ton)	1,200	300
	Reheating ingots (0·68 ton) ..	390	—
	Balance	1,200	1,200
		2,790	2,500

Conversion to Electrical or Mechanical Power:

Total available energy ..	2,500
Less slag value	650
	1,850

Thermal efficiency .. .. 15 per cent.

1,850 × 0·15 = 280 kilowatt-hours per ton of coal.



Heat Flow Diagram of an Iron and Steel Works.
(Sensible heat shown unshaded.)

From Table I it will be seen that one ton of coal produces 0·7 ton of coke, together with the other items shown, the heat values of which are given in the first set of figures.

Now 0·7 ton of coke will smelt 0·64 ton of pig iron, and the 6,000 units of heat energy in the coke are distributed as shown in the second set of figures.

Of the surplus gas, viz. 630 units at the coke ovens and 2,160 at the blast furnaces, i.e. 2,790 in all, about 1,200 can be made use of on the open-hearth converters and 390 in reheating the steel ingots.

Totalling up the heat available for conversion to electrical energy or mechanical power, we have 350 units from the tar, 650 from the slag, 300 which can be recovered as waste heat from the steel furnaces, and surplus gas to the value of 1,200 or 2,500 in all.

These units of heat energy—leaving out the slag—converted at a thermal efficiency of 15 per cent yield 280 units either in the form of mechanical power or electricity, and this on a coal consumption 50 tons per hour corresponds to an output of 14,000 kw.

We will take the case of a group of works equipped with four 70-oven batteries consuming 8,700 tons of coal per week, five blast furnaces each making 1,100 tons of pig per week, and sufficient open-hearth steel-furnace capacity and rolling-mill plant to convert the whole of the pig iron make into finished steel sections. 8,700 tons of coal per week at a steady rate of consumption is approximately 50 tons per hour.

On the other side of the account the power consumed at the works would be as shown in Table 2.

The blowing-plant requirements are based on 4½ tons of air per ton of coke, equivalent to 138,000 cubic ft. per ton of pig iron; theoretically it needs 1 kw. to deliver 1,600 cubic ft. of free air per hour under the usual conditions of temperature and pressure which, at a blower efficiency of 72 per cent, represents 120 units per ton of pig iron.

For the rolling mills I have taken 110 units per ton of steel, a high figure for rails and the larger sections and one which should safely cover most classes of work.

The sum of the demands on this showing would be the same as the nominal kilowatt output, and though some allowance might be made for diversity this would not bring the load within what I should like to call the dependable output of the generating plant, say 60 per cent of its full output. It must be remembered also that with the steel works shut down at week-ends, there would be more gas used at the steel furnaces during the working days, reducing that available for power. One should therefore allow for a stand-by supply of 40 per cent, or say 5,600 kw. On the other hand from the point of view of units an allowance of 15 per cent would probably be sufficient to cover the average deficiency of the generating plant, making the average output 11,900 kw. and the units per week 2,000,000, while the total consumption would be 9,900 × 168 = 1,600,000, leaving a surplus of 400,000 per week.

The figures given in Table I are based on the following values, which I think are fairly representative:—

Gas per ton of coal coked	10,500 cub. ft.
Gas burnt on the ovens	5,500 cub. ft.
Calorific value of coke-oven gas ..	430 therms (net)
Tar per ton of coal coked	100 lb.
Coke per ton of pig iron	22 cwt.
Gas from blast furnaces per ton of pig iron	165,000 cub. ft.
Calorific value of blast-furnace gas ..	100 therms
Slag per ton of pig iron	30 cwt.
Heat required at steel furnaces per ton of ingots	6,000,000 therms
Ditto for reheating	2,000,000 therms

all the gas values being at normal temperature and pressure.

The coke-oven results are those obtained with any well-known make of by-product regenerative oven operated under ordinary commercial conditions. About one-half of the gas produced goes to heat the ovens and the other half becomes available for outside use. Its calorific value with a benzol extraction of $2\frac{1}{2}$ gallons per ton may be taken as 430 therms, or some 10 per cent less than would be the case if the benzol were left in, a disadvantage which is compensated to some extent by the gas being more uniform in quality.

Coke-oven gas, which consists mainly of hydrogen and methane and burns with a high temperature, can be used for the production of power by either gas engines or boilers. It is not as suitable as producer or blast-furnace gas for gas engines because of sulphur and pre-ignition troubles, while for boiler use it has a high efficiency and gives a greater output than coal for the same heating surface. On account, however, of its good heating qualities it is being used more as fuel for the steel furnaces than for power purposes wherever the coke ovens and steel plant are in proximity, either alone or as an admixture with blast-furnace gas, and this is the use which I have assumed will be made of it.

The whole of the coke goes to the blast furnaces, with the exception of the breeze which can be used for calcining the ore or for other similar purposes.

The consumption of coke in the blast furnace may be taken at about 22 cwt. per ton of pig iron as a moderate value for the stone and ore smelted in this district. With some qualities of Cleveland stone and with manganese ores it is much more, while hematite ores being richer in iron require less. Various other considerations affect the amount of fuel charged to the furnaces, such as the temperature of the blast, output, and quantity of water in the ores and flux. The air or blast required to provide sufficient oxygen to convert the carbon (less what takes part in other reactions) into the reducing agent, carbon monoxide, is about $4\frac{1}{2}$ tons per ton of coke. It is delivered under a pressure of from 8 to 12 lb. and at a temperature usually exceeding 1,000° F. Apart from its principal function of smelting iron, the blast furnace may be looked upon as being a large gas producer in which about half the fuel is consumed internally at a high temperature and all impurities are run off in a molten state. The gas has a composition of about 28 per cent CO, 11 per cent CO_2, 2 per cent H_2, and 59 per cent N_2, which corresponds to a combustible value of 100 therms per cubic foot.

The usual criterion of the performance of a furnace in economy of coke is the ratio of CO to CO_2 in the gas; this value is usually a little under 3 : 1. If more of the CO is used in reducing the iron and other metallic constituents of the ore, less coke will be required in the furnace, and the fewer therms there will be in the gas; but this necessitates slower working and a lower tonnage output, while on the other hand the more value the gas has for power purposes, the more

TABLE 2.

Kilowatts Output.

Coal consumed per hour	50 tons
Energy per ton of coal	280 kelvins
Nominal output = 280 × 50 .. .. =	14,000 kw.
Minimum output = 14,000 × 0·6 .. .. =	8,400 kw.
Average output = 14,000 × 0·85 .. .. =	11,900 kw.

Kilowatts Load.

	Units required per Ton of Coal		Mean kw.		Load Factor		Maximum kw.
Coke oven auxiliaries Blast furnace ,, Steel furnace ,, ..	= 40 × 50	=	2,000	at	0·6	=	3,300
Blowing plant (120 × 0·64) ..	= 77 × 50	=	3,800	at	0·9	=	4,200
Rolling mills (110 × 0·68) ..	= 75 × 50	=	3,700	at	0·6	=	6,500
			9,500				14,000
Average output, units per week		=	11,900 × 168			=	2,000,000
Consumption, ,, ,, ...		=	9,500 × 168			=	1,600,000
Surplus							400,000

it pays to increase the charge of coke and to drive the furnace harder. The quantity of gas given off can be readily calculated from the gas analysis, as the percentage weight of carbon present in the sample is the same as that which the carbon charged to the furnace (less that going away in the pig iron) bears to the total gas. The air for the blast is usually heated by means of brickwork stoves of the regenerative type, which make the first call on the gas from the furnace. With the gas in its dirty or dust-laden state, as is customary, the stoves absorb about 45 per cent of the yield, equivalent to an efficiency for the transfer of the heat content of the gas to the air of not more than 50 per cent. This poor performance can be greatly improved by cleaning the gas and providing sufficient stove capacity. I have taken 30 per cent of the gas yield or 50,000 cubic ft. as being amply sufficient for the purpose, even at the higher blast temperatures. This brings the stove efficiency up to about 70 per cent. The kelvins of heat corresponding thereto are 930, and these added to the 2,010 units for "furnace reaction and loss" represent the quantity of heat absorbed in the smelting process, assuming that the other items are recoverable. There is included in this quantity the sensible heat of the gas, amounting to about 8 per cent of the total gas value, which is abstracted and lost at the gas washing or cleaning plant where the temperature of the gas gets lowered from about 500° to 90° F.

The quantity of slag produced at the blast furnaces depends upon the proportions of silica alumina and other non-ferrous materials in the ore and upon the amount of flux which has to be added to melt them out. From 25 to 35 cwt. comes away per ton of pig iron.

The heating of the basic open-hearth steel furnaces and mixer, which is the form of steel plant in most general use, is commonly done by means of a simple form of gas producer consuming about 6 cwt. of coal per ton of steel ingots and giving off a gas having a calorific value of 130 therms. Both coke-oven gas and blast-furnace gas can be and are used for this purpose, the former for preference, as a higher temperature of combustion can be more readily obtained. On the basis of this coal consumption mentioned there will be required—making allowance for producer efficiency and for the fact that no producer steam will be wanted—about six million therms or 1,760 kelvins per ton of steel. I understand that there is an advantage in using coke-oven and blast-furnace gases at the steel furnaces in that a more uniform supply of gas is assured than can be obtained from separate producers which are subject to mishandling and to variation in the qualities of fuel used.

The burnt gases from the open-hearth furnace leave at a temperature of about 1,100 F. There is consequently a great deal of waste heat, which it is found can be recovered by fitting boilers in the flues leading to the chimney stack. In America the practice of raising steam in this way has prevailed for some years past with a notable increase in economy, and in this country also most of the modern furnace plants are being equipped with waste-heat boilers. Induced draught is necessary to pull the gases through the boilers, but this enables the furnaces to work under more constant draught conditions and is found to increase their output considerably. Without boilers the outlet temperature is too high to permit of fans being used. About one-fourth of the heat supplied to the furnaces is available for the raising of steam.

The heat required at the soaking and reheating pits may be taken at 2,000,000 therms per ton or 580 kelvins. Part of this could be recovered, but I have not taken it into account.

Looking at the figures given in the table from the point of view of power production, the first available source of energy is the tar from the coke-oven gas in the by-product plant. An average yield is about 100 lb. per ton of coal carbonized, having a heat value of 500 kelvins. I might mention that practically all metallurgical coke is now made in by-product ovens. It is difficult to say what the market price of tar will be after the war and consequently what quantity will be available as fuel, but bearing in mind the increase in the number of coking plants it is probable that most of the iron works' tar will find a use for this purpose after the lighter oils and creosote have been taken off. Assuming that these amount to one-fourth by weight, there will be a residue containing, say, 70 per cent pitch which can be burnt under boilers with very satisfactory results and has an important advantage in comparison with the gaseous fuels in that it can be conveniently stored and used at times of heaviest load. I have brought three-fourths of the tar into the scheme and taken the heat units as 350; benzol I have left out of account.

The 650 units available from the slag represent the sensible heat in the slag as it comes from the furnaces. So far as I know, this heat has not been put to any commercial use hitherto, mainly because the gases and other sources of waste heat which are in a more useable form have not been fully exploited. It is, however, a possible source of energy.

Messrs. Bell Brothers had an experimental plant at work before the war at Port Clarence in which the hot slag was quenched under a stream of water as it came from the furnaces, and the steam so raised passed through an evaporator or heat-transfer vessel where it gave up its heat to another lot of water, forming the medium for a low-pressure turbine plant. It was found that the steam coming off the slag contained injurious and non-condensable gases and could not be used directly in a turbine. The slag leaves the furnaces at a temperature of 2,700° F. and has a heat content of about 1,000 therms per pound. By experiment it was found possible to evaporate 1,017 lb. of steam at atmosphere temperature and pressure per ton of slag and to obtain from this steam 24 kilowatt-hours in a small low-pressure turbo-generator. A description of the apparatus was contributed to the Iron and Steel Institute by Mr. W. L. Johnson.* An incidental advantage of this method of dealing with the slag is that it comes away in a highly granulated form and one which is more suitable for transportation and for many of the uses to which this slag

* *Journal of the Iron and Steel Institute*, 1914, vol. 90, p. 98.

is put; in fact, water-quenching of the slag apart from any form of heat recovery is the common practice where convenient tipping facilities are not available. Until, however, some means can be found for raising the slag steam under pressure it does not seem likely that its use will be profitable and I have therefore left it out of account.

The blast-furnace gas forms by far the largest item of available heat, and its use therefore calls for special consideration. I have estimated that after the requirements of the steel plant are satisfied there will remain 1,200 units available for power purposes, either with gas engines or for the raising of steam. Gas engines of sizes ranging from 1,000 to 5,000 h.p. have been built for driving both blowers and generators, and a considerable number are now in use. Boilers fired by blast-furnace gas require larger combustion chambers and, as in the case of furnace heating, are the better for a hot air supply to increase the flame temperature and radiation efficiency.

I have assumed that the whole of the blast-furnace gas will be cleaned of the dust which it contains, both for heating and for power purposes. The cleaning of the gas involves a certain amount of expense, and a consumption of power of about 2 per cent of its equivalent power value; but its incidental advantages are great and it is essential for a high thermal efficiency that the dust should be eliminated whether the gas is used in gas engines or under boilers for the raising of steam. The use of the gas in its dirty state has been the cause of most of the waste and lack of progress in the past, and this again has been because the question of cleaning it did not, owing to lack of means for the satisfactory disposal of surplus energy, admit of any clear issue under the old conditions. Roughly 50 lb. of dust come away with the gas per ton of pig iron, or, say, 25 tons from an average-sized furnace per week. Perhaps one half of it gets deposited in the stove and boiler flues, while the other half is discharged into the air to find a resting place where it may. The conditions are such that it is scarcely practicable to maintain water-tube boilers in operation owing to the blocking up of their tube passages, and shell-type boilers work with an extremely low efficiency. Beside the frequent boiler cleanings which are necessary the whole of the furnace plant has to stand for a day or two about every three months to permit of the flues and stoves being cleared of the great quantity of dust which accumulates. This periodic shutting down of the furnaces disorganizes the operations at the steel plant dependent upon them and interrupts the regular course of coke and ore supplies. If the greater return from the cleaned gas plus the disadvantages attendant upon its use in a dirty state are not sufficient to lead to the general adoption of gas cleaning, as I think they should be under most circumstances, the value which blast-furnace dust has recently acquired on account of its potash content may be a determining factor.

There are two systems of cleaning in vogue, one necessitating the use of a large quantity of water atomized and intimately mixed with the gas in suitable centrifugal apparatus from which the dust comes away as a sludge, and the other a filtering or dry method. Both systems rob the gas of the greater part of its sensible heat, and also by lowering its temperature reduce its combustion efficiency, the wet arrangement having the added disadvantage of introducing moisture to the point of saturation. Recently, and more particularly because of the demand for potash, consideration is now being given to an electrostatic method of dust extraction developed by Dr. Cottrell in America and used with great success, I believe, for the recovery of the valuable constituents of the gases from furnaces smelting the ores of metal such as lead and silver. It is conceivable that an electrical precipitation process may have advantages over the present washing and filtering method of cleaning in being able to pass the gas through at a higher temperature, and if the risk of explosion can be guarded against, may form the solution of this important and much debated question. It is of interest to note that a patent which made use of an electrostatic discharge was taken out by Mr. B. H. Thwaite of Glasgow in 1896.

I might now give an idea of the present condition of things from a point of view of fuel economy to show what a scope there is for improvement. In old-established Cleveland practice the surplus heat from the blast furnaces is converted into power by means of shell-type boilers in open settings and non-condensing steam engines at a thermal efficiency of about 5 per cent, and as a consequence there is little gas to spare, unless it happens that the stove capacity is insufficient and there is a high coke consumption. The advent of the exhaust-steam turbine has been taken advantage of in a good many cases, improving the thermal economy by another 5 per cent. It is here that the power companies have been able to effect a very considerable saving of coal, while the advantage to the iron masters has been great, not alone from the payment they receive for what otherwise would be a waste product, but by getting the steam returned to them again in the form of water. In the Middlesbrough district alone the boiler feed recovered at the power company's stations in this way exceeds 200 million gallons per annum.

Although the old-type reciprocating blowing engine has had its life prolonged by the exhaust turbine, the combination of the two is in the nature of a make-shift and represents a transition stage in the change from a partial to a complete use of waste heat. A further 5 per cent increase in efficiency is possible with live-steam turbines and a great deal more with gas engines. The relative merits of these two prime movers for both blowing and electrical generating comes up for consideration in every case where new plant is required and raises a question upon which there is no clear issue and hence much difference of opinion. The Council of the Cleveland Institution of Engineers recently appointed a Committee to investigate and report on the matter as it is one which the iron masters realize is now in need of a decision if they are to develop on right lines. I do not intend to enter upon a discussion of the arguments for and against the use of gas engines, as I have not time to do so, but from my own experience and all the information I can gather I am of opinion that steam plant at the present time best

fulfils the principal conditions of cost, thermal efficiency, and reliability, and possesses advantages over gas plant in being able to use up heat in other forms than that of gas. In view of the importance of the subject, in the interests not only of steel works practice but of power generation as a whole, the time seems to be ripe for another paper on the lines of that brought before the Institution in 1909 by Messrs. Andrews and Porter.* There has been a steady increase in steam-turbine efficiency since 1909, and the comparison of thermal results which existed at that time would not hold good to-day.

For a group of works such as we have been considering there would be required on a steam basis one turbo-blower per furnace, each about 1,000 h.p., and two turbo-generating sets of as large a size as possible, say 10,000 kw., to use up the remainder of the available heat, one or more motor-driven blowers being installed as a stand-by to the turbo-blowers. Gas engines might be used as auxiliaries to the steam plant if the circumstances were such that the higher thermal efficiency justified the increased capital and maintenance charges; they could then be built of the most economical speed and size and be run continuously for the sake of maximum economy without the usual expensive spares.

A 15 per cent thermal efficiency for modern steam plant falls a great deal short of what it is possible to obtain with turbines of large size, high steam temperatures, and other aids to economy, but on the other hand it is an advance on present practice in comparatively small stations. It is based on a boiler efficiency of 70 per cent, a steam consumption of 14 lb. per shaft kilowatt-hour for the blowers and 12 lb. for the 10,000 kw. sets, under the usual modern conditions of pressure, superheat, and vacuum.

There are no statistics available of the quantities of coal at present used in the several processes of iron and steel manufacture, and I can therefore only make a rough estimate of the amount which would be saved with a complete system of heat recovery such as I have described. Assuming that on the average the coke-oven and blast-furnace gases now supply the blowing plant, the auxiliaries, and one-fourth of the requirements of the rolling mills, then more coal would come into the scheme to the extent of that needed for three-quarters of the rolling mills and for the steel furnaces, an additional quantity which I should not like to put at less than 11 cwt. per ton of steel and which on last year's output would amount to about 5,500,000 tons per annum. This coal would be saved and there would still be left a surplus of energy above the works requirements.

I have assumed that the rolling mills will be driven electrically and that electric power will be used for all purposes except the blowing plant for which steam turbines are well adapted. The advantages claimed for the electrical reversing mill have been well substantiated in practice, as is borne out by the fact that there are at the present time under construction at least seven reversing mill equipments ranging from 10,000 to 20,000 h.p. in size, capable of doing the heaviest class of work, both roughing and finishing, with outputs of over 50 tons per hour. These new mills will together have a capacity of well over 1,000,000 tons of steel per annum. In addition there are numerous alternating-current motor continuous mill drives being installed in sizes of from 2,000 to 10,000 h.p.

An application of electricity which has not received the attention it deserves is that of locomotive haulage for shunting purposes in such cases as the one we are considering. Some years ago I investigated the conditions and costs of the present steam traffic at several works in the Middlesbrough district, the results of which were given in the form of a paper to the Cleveland Institution of Engineers.* The most striking feature was the high fuel consumption of the steam locomotives due to the unsuitable conditions under which they are operating. On a very close estimate of the amount of work done, the thermal efficiency comes out at well below 1 per cent and this shows the present steam shunting locomotive to be about the most inefficient form of prime mover in existence. A group of works such as the one we are considering would probably have 12 locomotives in commission consuming 4,800 tons per annum; in proportion to output the total consumption for steel works alone on this basis for the country last year would be 33 times as much, or 160,000 tons per annum. Taking for electrical driving a thermal efficiency to the motors of 10 per cent it is seen that there would be a saving of over 140,000 tons per annum. In addition, the well-known advantages of electric traction apply in a pronounced form, the only disadvantage and one which in my opinion is greatly over-rated being the use of overhead wires.

The most recent electrical development and steel works' practice, and one which has received a great impetus from the war, is that of the electric furnace. The great quantity of shell steel scrap about and the demand for the better quality steel has brought a number of furnaces into the district which are operating very successfully. To what extent electricity will be used for making ordinary mild steel I will not venture to predict. I think, however, more will depend upon the relative value of the product than upon the cost of manufacture. It may be that the quality of steel rails, for example, produced or partly produced electrically will be such as to command a price high enough to bear the additional cost of production. Whether this will be so or not it looks as if one or more electric furnaces will form part of the usual equipment of a steel works for melting down the rail crops and bloom ends, which may be taken about 10 per cent of the total make of steel. An average figure for melting and refining is 750 kilowatt-hours per ton, which may be compared with the heat absorbed by an ordinary gas-fired furnace, as shown in Table 1. At this figure the mean demand would not be less than 2,600 kw. and the maximum about 3,500 kw. This addition to the mean load brings it up to 12,100 kw., or nearly the same figure as that taken for the average output of the generating plant, so that practically all the units required would come out of the surplus

* *Journal I.E.E.* 1909, vol. 43, p. 3.

* *Proceedings of the Cleveland Institution of Engineers*, 1910–11, vol. 3.

shown in Table 2. The dependence of the works on outside stand-by plant would, however, increase to 0,000 kw. or thereabouts.

What I have tried to show is that there is, on a commercial basis, sufficient energy in the coal required for the blast furnaces' coke to perform all the various operations, thermal and mechanical, in and about an iron and steel works, but that owing to the large and sudden fuel variations there must be a stand-by plant capacity at hand for immediate use, and also a means for consuming what surplus energy there is available. Only in this way is it possible to obtain the full and safe use of all the heat energy of the coal at low capital cost, and at the same time to give that flexibility to the operations of the works as will secure its greatest adaptability to market conditions, accidents, or other changing circumstances. The balancing-up of the electrical end serves the further purpose of steadying the gas supply to the steel furnaces, as the gas going to the boilers can be diverted to the furnaces in case of shortage, and the tar may also be manipulated in like manner.

Until such time as there is sufficient co-ordination of the coke ovens, blast furnaces, and steel works as will avoid the destructive burning of coal, it is evident that a linked-up electrical system is still more necessary for picking up the waste heat wherever it may be found and passing it on to where it may be used. This is what has already been done to a great extent by the power companies. The advantages of complete co-ordination are, however, so considerable, apart from the question of fuel saving, that we may look for very great changes in the immediate future. One large undertaking in South Wales, for instance, has just announced its decision to spend between £3,000,000 and £4,000,000 over the next two years, a Middlesbrough firm has extensions of £2,000,000 in hand, and the programmes of most other iron and steel works are of the same order.

As an illustration of the scope of future electrical development, the total electrical energy to be dealt with on the figures I have mentioned, assuming them to apply to a make of steel of 14,000,000 tons, which according to Dr. Addison is what next year's output will amount to, and not including the power taken by the blowing plant, works out at 3,300 million units per annum, with a maximum load of over 600,000 kw.

I have not discussed the cost of providing the capital required to take full advantage of those fuel economies because prices are at present in an abnormal state, and the development changes necessary form part of a much larger subject which cannot be dealt with adequately from an electrical engineer's standpoint. It is, however, clear to me that the immense savings to be effected would yield an extremely profitable return on the appropriate capital. This is evidenced by the large and increasing expenditure now going on even at the inflated prices which prevail; and that the steel industry itself is not satisfied with its present methods and plant is shown by the reports recently presented on the subject by the Metallurgical and Mechanical Sections of the Committee appointed by the Iron and Steel Institute.

The potential value of blast-furnace gas has been known for many years mainly as the result of the pioneer work of the late Mr. B. H. Thwaite, who about 1897 went so far as to suggest that the sale of the gas for power purposes would enable blast furnaces to be kept in commission in times of depression in the pig-iron trade even if there were no profit on the iron. He evidently foresaw the possibilities of electricity distribution on a large scale at a low price, but failed to bring about any commercial development. Like many other and similar discoveries which have originated in this country, Mr. Thwaite's proposals met with a better reception in Germany and received there an application which has undoubtedly been an important factor in enabling the German industry to advance its trade at the expense of British trade.

Some reflections occur to me in looking back over the period which has elapsed since electrical engineering was sufficiently advanced to generate and distribute power for the heaviest class of machinery, in that opportunities have been denied it for want of that intelligent direction of capital which has been so notable in this country. Consider what a wastage of capital resources there has been as the result of misdirected and fraudulent enterprises in some way made attractive to investors who were not and in the nature of things could not be any judge of the manner in which their money was employed. There was a liquidation of public company capital alone of no less than £500,000,000 in the 10 years prior to the war. Then recall the overcrowding of the engineering professions and waste of young manhood which went on in the days when those of you who are my contemporaries found it not only difficult to select and follow any branch of engineering, but considered themselves fortunate to be able to get a job at all. Both capital and labour seeking profitable employment while at the same time economic opportunities existed, which if taken advantage of would have increased the production and wealth of the country enormously. It is also somewhat surprising considering the dependability of any fuel economy scheme upon electrical means for its realization how little this Institution has been identified with the enormous possibilities of electrical expansion which have stood ready to hand at any time for the past 20 years. One trusts that in future a great technical Institution like ours will have more influence on capital enterprise and will carry more weight with the men who are responsible for the government of the country. In that hope I see a greatly extended field of usefulness for the Institution, and a support to the electrical industry in the difficult days which lie before us.

WESTERN LOCAL SECTION: CHAIRMAN'S ADDRESS,

By R. Howard Fletcher, Member.

(Address delivered 12 November, 1917.)

An enormous amount of matter has been spoken and written on the question of scientific and technical research, but in the majority of cases the subject has, very naturally, been treated from the point of view of the individual author, with the usual result that the opinions as to the best method of procedure have been hopelessly conflicting. Even now there appears to be a most extraordinary confusion in the minds of many people between purely scientific and technical research. It is, of course, true that both types require careful training, knowledge, and an unlimited capacity for perseverance, but the objects in view are entirely different. Pure scientific research may be considered to be the following up of a line of thought and experiment, frequently of a most abstract nature, in the hope of establishing some scientific fact, and a man may do far worse than spend his life in the contribution of one small fact to the sum of scientific knowledge, even though it may not appear at the time to be of the smallest commercial or humanitarian value, for who shall say that this small fact may not be the foundation of some such far-reaching discovery as wireless telegraphy or X-rays? Technical research for industrial purposes is usually a very tedious investigation with the definite object of obtaining the most efficient material or process for some particular purpose, and, speaking generally, one of the most important points in such an investigation is to ascertain the cost of such material or process. It is therefore of the first importance that research of this nature should be carried out on a scale comparable with operations in works. This entails very great expense and consequently it is only the very large firm which can afford to equip a suitable laboratory, and the smaller firms have no choice but to co-operate for this purpose if they are to have the benefit of the newest knowledge and methods.

There is, of course, no doubt whatever that the closest possible co-ordination between science and practice is essential to progress, and we have reason for high hopes that this will to a very great extent be brought about through the efforts of the Imperial Trust for the encouragement of such research. Unfortunately the interests of the individual often clash with those of the nation, such a case as the following being by no means uncommon. The scientific man in the employ of some large concern attempts the solution of some particular problem, and, after a great deal of hard work and the expenditure of a considerable sum of money, arrives at a result which, though not a complete solution, yet gives his employers a great advantage over their competitors, and having borne the expense of this investigation they decide to keep their new knowledge to themselves and reap the benefit. Now it may seem rather extraordinary, but it is nevertheless a well-established fact that it is very rarely the case that a single brain is alone engaged on any particular problem, however abstruse that problem may be.

Probably the discovery of the planet Neptune is the most notable example of this fact.

In the case in question, it is by no means improbable that some other man in some other works is engaged on the same problem and, supposing that he too has some measure of success, the effect is likely to be the same, with the result that a cut-throat competition is started between these two rivals. The consequences are obvious: nobody profits to any extent; other competitors are squeezed out, and it is quite likely that a more complete solution may be found at smaller cost in some other country where knowledge is better co-ordinated and this particular industry gradually dies down and is finally lost to the nation. We can only hope that some satisfactory means may be found which shall overcome this difficulty, for it is undoubtedly a very real one.

I do not think it is the smallest exaggeration to say that the loss or absence of any industry is a very serious matter, and, where the particular industry is of vital importance, in an emergency it might well prove to be a national disaster. It will, I think, be a very long time before any of us forget that in the autumn of 1914 there only existed in this country one factory making searchlight carbons at a time when the quick supply of these was of the first importance, or that we had up to that time been almost wholly dependent upon our enemies for magnetos in spite of the fact that the enormous advantages of rapid motor transport had long been recognized. There are of course many other instances and it would be a simple matter to give quite a long list of really indispensable articles and materials for the supply of which we have hitherto been entirely dependent upon foreign countries.

Incidentally this is a magnificent tribute to the British Navy, and it has been abundantly proved that our faith in it was not misplaced. At the same time, that is neither the only nor the main reason for this extraordinary state of affairs. The real reason is that in this country practically everything of an industrial nature has hitherto been left entirely to private enterprise, whereas in foreign countries the Governments have very effectively assisted and financially supported the establishment of new industries on a scale which would have been far beyond the means of private enterprise, and still more beyond its capacity for taking the necessary risks. Fortunately, those in authority now appear to be keenly alive to the importance of this matter, and it is to be hoped that no time will be lost in taking the necessary steps to ensure that so far as is possible we shall in future be in a position of self-contained independence as regards both indispensable materials and the industries dependent upon them. I think we shall

all agree that British industry has not in the past been overburdened with Government assistance or even encouragement. We have only to take as an instance the question of wayleaves in order to realize what this means to our own industry. The linking-up of our numerous generating stations, the resulting economy in the consumption of fuel, and even the very price at which electrical energy can be sold are all inseparably bound up with this question. Surely therefore we have a right to insist that the procedure for obtaining wayleaves should be reduced to the simplest possible form and with the least possible waste of time and money.

It is quite impossible to over-estimate the importance of questions of this nature as, unless a really cheap supply of power is made available, our industries will be quite unable to hold their own in the period of commercial stress which will undoubtedly commence immediately after the war. The task awaiting all engineering companies, and particularly electrical companies, will be enormous. For the last three years all plant and machinery has been run to death while only the most important has been replaced. The huge deficiency in output for that period will have to be met; the demand for new plant will be enormously increased, and it is of course essential that no part of this demand shall be supplied, as in pre-war time, by importation. That there will be a tremendous increase in the demand for electrical plant and power is beyond question, and I believe that this will be largely due to the part played by electricity in the really wonderful acceleration in the output of munitions of war, for all power users have appreciated the fact that this would have been impossible without electricity. In many cases it has been a manufacturer's first real experience of the many advantages of electric driving, and we may be certain that in all such cases there will be no thought of reverting to former methods. Then again there are many purposes for which the use of electricity is growing very rapidly. The increase in the use of the electric steel furnace is most striking when we consider the former prejudice against it, and it has been amply proved that high quality steel castings made by this method are distinctly superior to those made by any other process. The electric furnace is also being largely employed in the production of the highest grade tool steels and the special alloy steels used in aircraft manufacture. Its many advantages, including a very considerable reduction in melting losses and the ability to use second-grade materials in the manufacture of high class steel are at last fully recognized, and there is no doubt that its use for such purposes is now firmly established on merit. There are of course many other applications of the electric furnace, such as the fixation of nitrogen, which seems likely to develop into a considerable industry. Steps are being taken in many directions to establish electrochemical works for various purposes of the utmost importance, and these should be most welcome to the central station engineer not only on account of the magnitude of their demand for power, but also by reason of the fact that in most cases there should be no insuperable difficulty in working on a restricted-hour basis. From the United States we hear of experiments in the production of synthetic petrol by an electrochemical process and the pickling of steel by an electrolytic method, both of which may become valuable industries. Then we have electro-culture, which is receiving a large amount of attention at the present time. Experiments with a variety of crops are being carried out in several districts in this country, but unfortunately a long time must necessarily elapse before results are known, so that progress is somewhat slow. Enough, however, has already been done to afford good grounds for believing that great benefits will result from this treatment. Instances are recorded in the case of wheat of an increase of 50 per cent in grain and 90 per cent in straw; oats an increase of 49 per cent in grain and 88 per cent in straw; potatoes, carrots, beet, and other roots 20 to 50 per cent; while young strawberry plants have shown an increase up to 80 per cent. It is a most interesting subject, and we hope to hear a great deal more about it before the end of this session.

The war has taught us that farmers are quite as valuable as bankers or manufacturers, and they should receive every encouragement and assistance and if, as seems probable, electro-culture should be found to render the farmer more independent of the weather, in addition to increasing his crops, it will be an enormous gain to the community, not only from the food point of view, but also from the fact that it will help to keep money in the country and free more shipping for those essential raw materials which are not obtainable in this country. This particular application of electricity will not in itself mean a large demand for power, but it should nevertheless be of value to the station engineer as a means of introduction to a class of consumer who has many uses for power which hitherto he has only been able to obtain by costly and wasteful means. Incidentally also it should be a useful assistance in the obtaining of wayleaves in country districts, as even what I can only term the natural cussedness of the landowner is likely to be considerably modified where prospective benefits are to be obtained by the granting of a wayleave.

Many more instances might be given of the demand for plant and power which will have to be met, but these few are sufficient to give some idea of the sort of conditions which are certain to obtain immediately the war is brought to a close, and these conditions will not be confined to our own and other engineering industries, but will undoubtedly apply to industries of all kinds. It is of course thoroughly well understood and appreciated that such conditions cannot be met without very careful organization; in fact such terms as re-organization, reconstruction, co-operation, co-ordination, etc., have been household words for some time past. They are, however, a very great deal more than mere words, for it is not too much to say that the ideas which such terms express are of really vital importance to the continuance of the British Empire. For if we are to succeed in maintaining our position in the world it is absolutely essential that we should make the fullest possible use not only of all material, but also of all mental and physical effort. We are well aware that our enemies have for a long time been giving the very closest attention to these matters, and we may be

quite certain that their preparations to meet the strenuous times ahead of us will be made with the most painstaking care and most minute detail. It is probably owing to their undoubted thoroughness that so many people in this country appear to think that Germany has a sort of monopoly in the power of organization, but we have only to consider how quickly and efficiently our workshops and factories were adapted without any warning to the production of munitions of war in order to negative that theory once and for all. A very great deal has already been done towards the attainment of these ends, but an enormous amount still remains, and it cannot be done too carefully or too quickly. We have had one very severe lesson in the dangers of unpreparedness, and though it is even now very difficult to realize how nearly fatal was our condition in that respect in 1914, yet I believe that we have taken that lesson to heart so deeply that we shall not again run a risk which would certainly prove fatal in an industrial conflict. Before leaving this subject there is one point with regard to organization in industry which is, I think, of some importance. Any thorough organization implies a more or less high degree of specialization if it is to be really efficient, but there is always the danger that specialization may be carried too far. For while a very complete and intimate knowledge of one's own particular branch of a subject is of infinitely more value than a smattering of many subjects, this should not be attained to the exclusion of all else. As a nation we undoubtedly possess a very marked individuality, and in my opinion it would be a very serious misfortune if this characteristic should become atrophied by condemning our youth to enter a narrow groove at an early age.

Now in all this remodelling of the industrial edifice with its main objects of increased production and maintenance of quality in the product, there are of course many problems to be solved, but the majority of these almost pale into insignificance compared with the question of the existing relations between employers and employed. The prime necessity in dealing with this problem is to find some means of removing the feeling of mutual suspicion and distrust which at present characterize their negotiations, and are in reality the foundations of all the trouble. Members have doubtless read what is known as the "Whitley Report," with its suggestion for the formation of a series of trades and industrial councils composed of members of trade unions and employers' federations. In principle such a system, though somewhat cumbrous, is of course perfectly sound, but I think it is obvious that it cannot be a practical success unless these two requirements are fulfilled. First, it must be thoroughly understood and fully appreciated by all parties concerned that the object of this machinery is not to settle disputes but rather to remove at its source any cause which might lead to a dispute if allowed to continue, and to enable all parties to work amicably together for the advancement of their particular industry to a high degree of prosperity, with the necessary provisions to ensure that all parties shall receive an equitable share in the benefits resulting from such prosperity. The other essential requirement is that every member of each council shall be a real and accredited representative of his particular body, and I firmly believe that if this question of representation can be satisfactorily solved we shall be well on the way to a lasting industrial peace. It is, however, very far from being a simple matter. If every worker in any particular industry were a member of his trade union, and every employer in that industry were a member of his federation, the difficulty, though greatly simplified, would not be wholly overcome, for there would still remain the chance that, though the trades council might be in perfect agreement, the body of employed, or perhaps even of employers, behind the councillors might refuse to abide by the terms of such agreement. We all know that this sort of thing has happened more than once, and it seems to me that if we will go back far enough we shall find that this discreditable state of affairs is primarily due—on the part of the worker at all events—to a desire, of somewhat modern growth, for an improvement in social position, and this desire is naturally greater when the position connotes better pay and probably less arduous work. Whether this view be correct or not there is no doubt that membership of these suggested councils will be eagerly sought after, and it is most unfortunately a fact that the man who shouts loudest and most often has the power to sway his audience, however crude and undeveloped his arguments may be, and this is especially the case when the audience is in a discontented humour. The result is that in many instances the elected representative is a man whose study of his subject is very superficial and who probably knows nothing of the complicated nature or cost of distribution and sale. Such a man is invariably suspicious. Now it is fairly certain that the arguments put forward by a man of this type for election purposes will never have been really convincing, and he will not have succeeded in imbuing his supporters with a very deep faith in his knowledge and judgment, and moreover he has become an object of some envy owing to his now having comparatively light and congenial work, greater freedom, better pay and, I believe most desirable of all, an improved social position. Under such conditions, he will soon begin to lose touch, and it only needs the arrival of an agitator with perhaps a more glib tongue or more fiery eloquence and the so-called representative is finally discredited. I hope it will not be thought that I have laboured this point unduly or that the cause I have suggested is too small to deserve notice, for it undoubtedly exists and has its influence, even if it has not the weight which I have attributed to it.

These and many other matters of the highest importance are on all sides receiving the closest attention at the present time, but I think we shall all agree that it is always well to ventilate ideas as to the causes of trouble, as it is only by thorough investigation that the remedies can be discovered.

The need for these remedies is very urgent, for we must not for a moment lose sight of these two points:—First, there never has been and in all probability there never again will be a chance like the present. And secondly, whatever men's sentiments may now be, trade will inevitably go to those who are in a position to meet it adequately.

MANCHESTER LOCAL SECTION: CHAIRMAN'S ADDRESS,

By C. J. Beaver, Member.

(*Address delivered* 13 *November*, 1917.)

Synopsis.

General effects of the war on the world's industry.
Its effect on industrial progress in our own country.
Its focusing effect on our views.
Necessities revealed by the focusing process :—
  For reforms in fiscal and administrative matters.
  For reforms in matters of social economy and the relations of capital and labour.
  For reforms in patent laws.
  For reforms in education.
  For conservation of the natural resources of the country.
  For linking up scientific research with all phases of industry.
  For co-ordination of effort and correlation of results.
Our part as an Institution.

The conditions of war which are unfortunately still with us have wrought kaleidoscopic changes in the world's industry. In our own country and in the countries of some of our allies, production has had to be enormously augmented in some directions and restricted in others, while a number of industries have been diverted to supplement the supply of material required for the prosecution of the war.

Countries which have been invaded by the enemy have had their industrial positions seriously damaged —in one or two cases practically ruined. The industrial status of certain neutral countries and of countries playing only a partially active belligerent rôle has been considerably improved by reason of the opportunities afforded for the filling of the gaps thus created in various parts of the world's commerce. The kaleidoscope will continue to operate—there will be no industrial *status quo ante bellum*.

In our own country the marvellous creation and development of our fighting forces has been fairly paralleled by our industrial mobilization and the response of industry to the call of the nation's need. This response has been made by no body of men more readily or efficiently than professional and industrial engineers. From the apprentices who volunteered for sappers' duties in the field to the captains of the engineering industry and the professional engineers who have engaged in organizing—and more important still—reorganizing work in Government departments, all have given of their best.

Although the industrial machine has been hampered by many things and in divers ways, the mobility and adaptability of the whole has furnished a demonstration of our country's industrial potentiality which augurs well for the strenuous years ahead. Progress in many directions has received such an impetus that industries or important branches thereof in which we were being outstripped through various causes, have been grappled to our industrial system and become part of our national assets. All our national institutions, traditions, and habits of thought have been tried in the fire, and we have seen some purified by the process, while on the other hand some have not survived the ordeal, or at least have not justified the confidence previously reposed in them. It seems to me therefore that there will be no more favourable time than the present, while the new aspects are fresh in our minds, to review a few of the factors which in my opinion will be of outstanding importance in the industrial Renaissance period which is dawning.

The views of all, from the narrowest vision of the individual to the most comprehensive outlook of governing bodies, have been forced to undergo a focusing process; and as a result relations and aspects which were previously unrecognized, or at least only dimly appreciated, have been revealed more or less in their true proportions.

Individuals who were unconnected with industry, ignorant of political economy and far removed from knowledge of the relation between industry and national prosperity, people who abjured chimney stacks and factories as blots inflicted on the landscape by savage and uncultured persons, and who never realized that their incomes primarily depended on the country's industrial position in the world, have come to hold broader and more logical views.

Manufacturers, merchants, and other commercial people realize that a more insidious form of war really existed for many years prior to the commencement of its military phase, and they see that only by joining forces—the merchant through his chambers of commerce and the manufacturer through his trade associations—can the industries with which they are connected become reasonably powerful entities in the whole scheme of national affairs, and obtain that support from constitutional sources which is necessary to their survival of subsidized foreign competition.

In similar manner the manufacturers' and traders' associations recognize that only by combination in comprehensive schemes of federation, embracing every fundamental feature from education onwards, can they wield sufficient influence in national and international affairs to do their part in ensuring the industria supremacy of our empire.

The engineering institutions and other scientific bodies perceive clearly that the maximum benefit to the nation from their functions and activities is obtain-

able only by co-operation with the federated associations advisory councils, and other bodies which the necessities of the times have called into being.

The Imperial Government conclude that the assistance which they formerly gave to scientific research and its industrial application is entirely inadequate to meet the conditions, not merely created, but revealed by the effects of war, and they have hastened to make good the deficit. The Governing Bodies of our Overseas Dominions have moved in synchronism with the Home Government and much preparatory work has already been accomplished.

This focusing process has revealed or accentuated many needs which are vital to our industrial progress and development; for instance, the necessity for reforms in connection with fiscal and administrative matters, patent laws, education, social economy, and the relations between capital and labour; the necessity for the application of organized scientific methods to the economical utilization of our natural resources and means of sustenance; the necessity for linking up scientific research with all phases of manufacture and industry on the broadest possible basis, and fostering all possible means to that end; and that most essential need of all—which concerns every individual and every body of individuals, from the scientist to the man in the street, from the educational authorities and the professional, industrial and commercial organizations to the Imperial Government itself—the need for co-ordinated and progressive effort and for the correlation of the results thereof.

These necessities cannot be said to have been previously unappreciated by deep-thinking men, but they have been thrown into strong relief by the fierce light which the war has cast on the problems of civilization, and their proportions and relations have been made clear by the enforced focusing process to which I have referred.

I do not propose to dwell on those which have a political aspect except to point out that as regards fiscal matters the absence of a definite Government policy tends to discourage enterprise, and that as regards such administrative matters as are directly connected with industry, scientific training and a knowledge of industrial affairs should be regarded as essential qualifications in those who handle them.

Closely related to this point is the matter of advisory councils and committees in connection with Government departments, and specially constructed committees on various educational, scientific, technical, and industrial subjects. Those which existed in pre-war days were often as lethargic as Royal Commissions, but those which have been since called into being have generally shown themselves to be in accordance with the spirit of the times and are accomplishing much good work. In principle their objects and functions are excellent, but it is important in the interests of efficiency that their status and composition should be such that comparative independence is maintained and all stifling bureaucratic influences avoided.

Questions of social economy, with which are bound up the relations of capital and labour, are rather outside the scope of our considerations this evening, but it may be permissible to note in passing that the economical situation in this country is such that the necessities of life—to say nothing of the luxuries—are bound to be dearer after than before the war because of the inflated national credit.

The wages of the working classes will necessarily advance to at least a corresponding extent.

The wealthy classes who have financed the Government during the war will be at least no worse off than before.

The merchant and the manufacturer will also not suffer (except of course through temporary depression of trade) because of the unerring principle that the consumer pays.

The middle class—or at least that portion known as the salaried class—will be affected by neither the economical necessities nor the automatic compensations of the situation. Unfortunately this class represents the backbone of industry; and managerial, engineering, and technological careers will consequently appear at a disadvantage to the rising generation by comparison with commercial careers and detached businesses or professions in which the return is commensurate with individual effort and is governed by economic laws.

This situation is clearly imcompatible with the requirements of the nation's industries.

The reform of the patent laws should be a corollary to the attainment of progress due to the linking up of scientific research and industry. The chief points which call for reform relate to the compulsory working in this country of foreign-owned British patents and the obtaining of compulsory licences. Legal powers for the latter have been in existence many years, but the costly and cumbrous procedure entailed and the doubtful value of the result (by reason of the ambiguous construction, camouflage, and, frequently, the speculative character of foreign specifications) have led to very few manufacturers availing themselves thereof.

Again, the Act designed to ensure compulsory working, in this country, of foreign-owned British patents within a period of four years from date of application, which became law in 1908, was shown in the following year to have been fouled by ambiguous drafting, a ruling by Lord Parker deciding that in an application for revocation the burden of proof was on the applicant, whereas it should obviously be on the patentee. So recently as 1914, further efforts were made by the Associated Chambers of Commerce to get this point amended, but without success.

Since the outbreak of war some drastic emergency steps have been taken under the Defence of the Realm Acts, but it is clear that when these arrangements are suspended at the end of the war, the whole matter will call for serious reconsideration, and steps should be taken to make it an imperative condition that the manufacturers' views should have due weight given to them.

It is, by the way, a curious fact that the war has not interrupted communication between the British and the German Patent Offices. British applications for patents in Germany under the Convention go

through, arguments arising therefrom are conducted, and patents are granted practically as in peace time. The reason of this is, that by express permission of the Government the necessary negotiations with enemy countries may be carried out through an intermediary in a neutral country. In some of the countries of our Allies, however, applications are postponed till after the war.

Recently Sir Robert Hadfield and others have strongly advocated an Empire patent system with uniform practice and conditions regarding such matters as period of protection, fees payable by the inventor, and so on. This is extremely desirable and so far as a layman can see should not be outside the realms of possibility. Although one seldom encounters the necessity to do so, it is said to require the filing of 40 separate specifications to obtain complete protection in all parts of the British Empire. Obviously the advantage of only having to file one patent would be enormous, and the reduction in cost to the patentee would be very considerable.

With regard to the period of protection, while there appears to be no good reason why in Canada it should be 18 years, and in most other parts of the Empire 14 years, there appears to be some ground for the contention in some quarters that the latter period is not long enough. It might be possible to differentiate between various classes of invention. It is true that under existing conditions extensions may be granted on application, but there are many cases of the utmost importance to industry where the commercial development of an invention may entail great expenditure of capital and time before a commensurate reward is earned by the patentee, compared, for instance, with the production of a small and easily manufactured article or piece of apparatus.

In any case, whatever measure of reform may be contemplated, the important point is to ensure that the errors of the past shall be avoided by seeing to it that the advisers to the responsible minister of the Crown adequately represent the economic and industrial interests of the country.

Educational reforms, especially such as relate to the higher scientific training in our technical colleges and universities, have been closely considered and fully discussed of late.

Looking first at the broad aspect, in order that our anxiety for scientific training shall be balanced and our view shall not be distorted, let us realize that the necessities which seem so apparent to us now are not new, and that progress in educational matters is exceedingly slow. So far back as 1873, Professor Frankland in his Presidential Address to the Chemical Society made remarks on the subject which are equally appropriate to-day. In referring to the progressive improvement in the Society's work he said:

> "It must not be for a moment imagined, however, that we have in this important matter taken the position which we undoubtedly ought to occupy as the nation holding the first place in wealth, trade, manufactures, and State revenue."

and went on to express his conviction that—

> "the progress of physics, chemistry, and biology is intimately bound up with the nature of the training prescribed by the governing bodies of universities for students of these sciences, and that until a profound change is made in the awarding of prizes and the granting of degrees in science in this country we shall look in vain for any substantial improvement in the prosecution of experimental investigation."

Even if we take into account that 40 years ago the connection between science and industry was almost negligible and the present-day stimulus therefore lacking, the progress of education and the recognition of science has been unconscionably slow, and the present-day claims of the sciences as opposed to the classics in our educational schemes may appear to be almost revolutionary.

This involves—still from the broad aspect—a balanced consideration of the rival claims.

If we postulate—as I think we may—that the ultimate object of education should be to train and guide the development of the inherent mental capabilities of the individual to the good of mankind, it would appear to be sheer illogical conservatism to utilize the classics to that end and to neglect the sciences.

The essential difference between classical and scientific education is that the former delves into the dead past, while the latter is concerned with things of the future, of progress, and the unravelling of the mysteries of the universe, and must therefore tend to develop a more virile and critical intelligence.

In these times of stress, however, there is a danger of taking an unbalanced view, a liability to go further than advocacy of the reforms required to set our house in order, and perhaps a tendency to demand a revolution in our methods. In a general way history shows that progress of all kinds consists more or less in alternations of revolution and reaction rather than in process of uniform development; but a closer examination shows that the more primitive the conditions the more violent is the action and reaction; and that, conversely, the more civilized the affairs concerned, the greater is the amenability to uniform progress. Education is surely the acme of civilized affairs, and the greater therefore the ultimate harm which would accrue from a heavy swing of the pendulum. The reaction would undoubtedly be detrimental to scientific progress.

While urging reforms, therefore, I would also plead for the avoidance of revolution. Classical education is as necessary to the development of civilization as scientific; and without the humanities—without the literary and artistic aspects of life—the wheels of progress must be like the wheels of the Juggernaut car.

Let us not conceal from ourselves that the present demand for scientific training is, to some extent at any rate, due to blind faith in its efficacy as a remedy for our industrial backwardness; and let us remember that if our aims in education are utilitarian we tend to create "monsters" instead of promoting the best interests of mankind.

Passing to the more detailed essentials of educational reform I would urge that, as regards general education, time formerly given to classical studies should be encroached on for science subjects. In public schools facilities for scientific training should be greatly augmented and scientific subjects given due prominence. In fact, scientific knowledge should gradually come to be regarded as part of the intellectual equipment of an educated man and become reflected in the habits of thought of every citizen, independently of any tangible application of science in his daily round. Such general scientific education will tend to lay a better foundation for the subsequent technical training of the industrial technologist, as well as for the university training of the man who may subsequently specialize in some branch of pure science.

Matters relating to specialized curricula in our technical colleges and universities, the provision of funds for specialized scientific training, the conferring of diplomas, honours, and degrees to hall-mark the attainments and qualifications of students, are somewhat outside our purview this evening. There are, however, two outstanding points in this connection which I should like to emphasize. First, the desirability of making greater use of post-graduate courses where these already exist, and providing them where they do not; for these constitute the means whereby the industrial research man may keep in touch with the best modern methods of pure research. Secondly, the vital importance of attracting the best men to the chairs of our universities, professorships in technical colleges, and the headmasterships of our schools; the provision of means to this end should be treated as a national consideration of the most urgent character.

The scope of our technical schools is unfortunately cramped by the varying requirements of different industries and industrial centres, and, further, the growth of scientific knowledge is so rapid that the efficient planning of curricula becomes increasingly difficult. Lack of time compels me to resist the temptation to dilate on the importance of this matter of syllabus design, but it must be emphasized that the more circumscribed the range of set courses or stages of instruction, the less chance we have of developing that mobility of thought and the analytical type of mind in the student which is essential to the efficient attacking of industrial problems by scientific methods.

The wider inclusion of scientific teaching in general education will help out these drawbacks to an appreciable extent, but the syllabuses of our technical schools must keep pace with the strides of pure science, so as to cover more ground in the limited time at the disposal of the technological rank and file. This particularly applies to evening classes, and here again the situation must be relieved by employers allowing their young people a proportion of their working time for technical studies. At present only the larger industrial concerns do this. One of these, through the splendid efforts of our senior vice-chairman, Mr. Fleming, has gone further still and established a day school for shop apprentices who have not had the advantage of technical school training.

It promises well for these necessary educational reforms that the importance of a broad foundation providing the potential for explorations into various realms of scientific and industrial research is being increasingly appreciated. This is evidenced by the number of reports of committees on the organization of various industries and the scientific training of men engaged therein, of which a brilliant example is the Report on Engineering Education and Research of July 1916, signed by Mr. A. P. M. Fleming and Professors J. C. Maxwell Garnett and Miles Walker. The sequel to the issue of this Report is the recent formation of a powerful committee representing all the chief engineering institutions, associations and federations, and educational bodies in the country, the latter including universities and technical colleges of university rank and the Board of Education. Briefly the objects of this committee are to form an organization to deal with the co-ordination of engineering training and the promotion of educational facilities to that end.

Passing to the matter of the conservation of our natural resources, the economical utilization of fuel obviously claims first attention. It is closely bound up with the matter of cheap and universally available power supply, which is clearly a vital and fundamental necessity of industry. Both branches of this wide subject have recently received, and are still receiving much attention. Matters relating to the classification of coals, carbonization and gasification processes, and other treatment bearing on the recovery and economical use of the various resultant products, are being handled by the Fuel Research Board. The schemes of research indicated in the recent report of this Board, including an announcement of the proposed establishment of a fuel research station at East Greenwich, will be fresh in members' minds.

With regard to the generation and distribution of power, considerable steps have been taken in the direction of making the most efficient use of existing power plants, and a general linking-up scheme has been propounded whereby the power requirements of the country may be served by about 16 systems instead of something like 600.

With regard to new power-plant work in the future, recommendations of a far-reaching and more or less concrete character have been made dealing with such matters as the most economical sizes of generating stations and units of plant and the most efficient transmission voltages.

The whole subject from winning the coal to distributing the power has called for the co-operation, under Government auspices, of mining, chemical and electrical experts as well as the organized support of the various scientific and engineering bodies. Differences of opinion have been revealed as to the soundness of certain of the recommendations which have been made, but the net result when all these differences have been compromised cannot fail to be of enormous benefit to our industrial progress.

At first sight the aspect of natural resources which relates to what I have called means of sustenance may appear to have little reference to electrical engineering, but it is at least worth a passing glance. The

withdrawal of many millions of men from productive enterprises has affected the supply, and transport difficulties have prevented the normal distribution throughout the world of food-stuffs and the fertilizers on which they depend.

Conditions resultant on the war have sharply enforced on our notice the truth of the forecasts of that far-seeing scientist, Sir William Crookes, relating to the effect of the depletion and unfavourable distribution of the world's stock of natural fertilizers on its food supply, and the result has been an access of interest in electrical processes for the fixation of nitrogen.

The electrical stimulation of plant growth has also been brought to the fore, and although for various obvious reasons it has made little headway during the past 20 years, there is probably a fairly wide future before it.

It is, by the way, a curious coincidence that the same type of electrical plant which is used for electro-culture is now coming into use (primarily for reasons of economy) for the electrostatic precipitation of many noxious fumes and vapours, which, as effluents into the atmosphere from chemical and smelting processes, have put thousands of acres out of commission as food-producing areas in many industrial districts.

The next necessity of those which I enumerated a few moments ago—the linking-up of science and industry—is one which is of particular interest to us as an Institution, because in our ranks we embrace representatives of almost every phase of the matter; physicists, scientists, and professors representing pure research and scientific training, technological specialists representing industrial research, and manufacturing and operating engineers representing the application of the varying degrees of scientific research to industry at large.

Further, the major portion of our activities are and always have been, broadly speaking, devoted to this linking-up of science and industry. The majority of the papers read at our meetings are more or less based on demonstrating the connection, in various subjects and in different directions, between primary scientific principles and industrial accomplishments, and our discussions thereon usually include the expression of views from all the grades of men I have just mentioned.

This special interest which we as an Institution therefore have in this portion of our survey this evening, coupled with its fundamental importance, leads me to assume that no apology is needed if I dwell on it for a few minutes to examine it in some detail.

In the first place, everybody, from the man in the street upwards, is placing great reliance and faith in the benefits and advantages to be obtained by linking up scientific research and industry. It has become almost a fetish to the general public. We must therefore be careful not to look upon it as a universal panacea for all our industrial ills. The more one knows of both ends of the relation the less inclined is one so to regard it. Neither should we gaze too ardently on the ultimate desideratum, lest we neglect to give sufficient attention to the means of attaining it.

In the next place it is easily apparent from a broad survey of the industrial field that the relationship between science and industry is much closer in some industries than in others; and again in various branches of a given industry the breadth of the dividing gulf varies, and further, in the details of a single branch some matters are much more amenable to scientific treatment than others.

Perhaps the best case one can take as an illustration is the chemical industry. Its relation to pure science is perhaps more direct and less complicated than in any other industry comparable with it in magnitude and scope, and yet in some parts of it the gulf is both wide and deep. Its branches vary from, say, the manufacture of definite chemical substances, for instance, fine chemicals, dyes, optical glass, explosives, etc., to manufactures in which, although definite chemical processes are involved, the products have an indefinite chemical composition, such as textile, paper, leather, and ceramic goods.

In the former case there is sometimes little difference between laboratory and commercial scale operations. In the latter the operations are often of the crudest description and the degree of chemical control very meagre.

The electrical industry—having the advantage of being comparatively modern—has, broadly speaking, its foundation in scientific research and its general structure largely built up on industrial research.

There are, however, many other important industries which have been very largely built up on an empirical basis, and in addition subdivided so that their components and products pass through several isolated branches of those industries before they are completed. They may even for economic reasons have to go out of the country for certain processes to be performed in the course of their production.

The textile industries and some chemical manufacturing processes furnish instances of this.

The gulfs to be bridged in such cases are enormous, and the linking up of science with such industries must obviously entail extensive preparation by industrial research for the ultimate establishment of connection with pure science.

A further general aspect of the matter is that in any industry or branch of an industry there may be several lines along which research may be profitably conducted. They may constitute distinct engineering, chemical, electrical or physical problems, although more usually combinations of these separate lines will be involved.

According to the scientific status of the industry concerned, according to the abstruseness or otherwise of the problem, according to whether the problem belongs to a distinct branch of science or is dependent on a combination of such branches—for instance electrical and chemical—and according to whether it is capable of being detached from its industrial environments for scientific treatment or has to be considered in conjunction with its rule of thumb trammels, so it falls within the scope of either the pure scientist or the industrial research man.

It therefore becomes apparent that the sequence of progress may be different in various parts of the in-

dustrial field, because in some parts an industry may be founded on the discoveries of the scientist or physicist, in others improvement may be attained in consequence of such discoveries, while in others—perhaps the most difficult of all—an industry or a branch of an industry may have to be painfully dragged into the light of science in order to be operated on, so as to ensure for it a healthy and progressive future.

In order to cope with the requirements which I have briefly described, it is clear that various grades of treatment are demanded, and it may be useful at this stage to review them.

We may regard scientific research as the pure scientific work carried out by physicists and scientists with the sole object of widening the bounds of scientific knowledge; and we may define industrial research as technical investigation having more or less directly utilitarian objects such as the production or improvement of materials, processes, and manufactured goods.

There is an intermediate grade of research usually classed as scientific, consisting of more or less detached investigations into fundamental problems of industry and manufacture, and the accumulation of scientific data which constitues or should constitute the basis of industry.

For the sake of brevity we may call those engaged in these three grades of research, the scientist, the technologist, and the consultant respectively.

It is obvious that no one grade of man can satisfactorily fulfil the requirements of more than one of these grades of research. His fitness for either depends on his education, training, temperament, and mentality. Just as in literature the character and temperament determine the choice of words and the ordering of phrases—and in the arts the method of expression of an emotion or conception—so in science the scheme of procedure and the method of attack depend greatly on the mental and temperamental characteristics of the investigator. Each grade has its broad characteristics and each sphere of work has to some extent its limitations which must not be disregarded in any general scheme of linking up science and industry.

Let us consider for a moment this question of characteristics and limitations. The pure scientist is a product of the highest training that can be devised and afforded by our universities, the greatest intellectual asset a country can have. His work is necessarily more or less specialized; in fact his value from the point of view of scientific research is almost proportional to the degree of specialization. (In saying this I am not unmindful of the drawbacks of narrow specialization, but I think we may anticipate that co-operation between individual specialists will accompany the more general co-operation towards which the whole community is moving; and, moreover, I think we may safely predict that our broad educational reforms will produce men of such calibre as to make Mr. Kipling's admirers regret that he ever described the scientific man as "the unrelated animal—the beast without background.")

In addition to his close specialization, a general characteristic of the physicist or pure scientist is, for reasons which are mainly traditional and temperamental, lack of sympathy with the industrial application of science. By reason of the detachment consequent on these characteristics the pure scientist is obviously far removed from constituting in himself the required link with industry, and in fact it would not be in the interests of efficiency greatly to disturb the independent and academic character of his work.

A point worthy of note in connection with the work of our scientists and physicists, and one which undoubtedly has a relation to our national characteristics as compared with those of other nations, is the absence of speculation and eagerness for precedence and notoriety which is painfully apparent in some other countries.

The technologist has up to the present usually been the product of our technical schools and colleges. True, such positions as chief designers in electrical engineering works, chief chemists in chemical factories, and so on, have demanded university-trained men, and as industry and science draw nearer the greater will be the demand for men of the highest qualifications and scientific attainments.

Until recently, however, the general state of industry with relation to science has not been compatible with the technical adaptation, as it were, of university-trained men, and on the other hand their training has been too academic in relation to the state of industry.

The tendency for this state of things to pass away is instanced by a recent advertisement issued by British Dyes, Ltd., to the effect that they were arranging the chemical superintendence of some new works and were "prepared to accept applications from chemists with manufacturing experience or from university-trained men desirous of entering upon an industrial career."

The wording of this advertisement appears to have a peculiarly interesting significance, in that it indicates the opinion that in an important enterprise in which science is closely related to industry very responsible positions can be efficiently filled by either the scientist who is prepared to approach industry, or the technologist who possesses specialized experience. In other words, the scientist may step down or the technologist may step up.

With regard to the sphere of the technologist, a great deal depends on whether the particular industry or branch of industry to which he is attached is a comparatively new one which has had the advantage of a scientific basis, or an old one which lacks that fundamental advantage. In the latter case the difficulties are very much greater than in the former, because many weaknesses, inefficiencies, and inconsistencies may be masked by the skilful and dextrous handling of them by skilled operators, so that until all their ramifications have been investigated they may not appear as problems calling for scientific investigation, although at the same time they may constitute a serious obstacle to progressive development until the technologist has stripped them bare. The vital matter of the perception of the problem therefore devolves upon him. But the technologist, whether he be engineer, chemist or specialized industrialist, is not generally, by reason of his training and environment, capable of approaching or appreciating to the full the work of

the pure scientists in all the manifold directions which bear on his work.

The trend of scientific education, the progress of industry towards scientific methods, and the consequent release from drudgery of the technologist so that he can make efficient progress in industrial research, combine to demand that his status and training facilities shall be improved. When this is accomplished he will constitute the most efficient link we can have between science and industry because he will be potentially able—by reason of his scientific equipment on the one hand, and experience on the other—to span the gulf which separates them at almost any desired point.

The scientific consultant has been in the past a kind of pioneer of science in industrial territory, and it was to him rather than to the physicist or pure scientist that the manufacturer appealed to for help over industrial stiles. He has not, however, usually been in such intimate contact with the ramifications of specialized manufacture as the technologist, and the demand of the manufacturer for an occasional scientific sprint in a given direction has been of limited use to industry, and at the same time has not tended to glorify science; for instance, the sum total of scientific knowledge on some subjects consists of the results of researches made for the purpose of law suits.

In recent years the manufacturer has in many cases been able to appeal for scientific information to such sources as the National Physical Laboratory, the Imperial Institute, and the Research Panels of his professional institutions, trade associations, and chambers of commerce; but valuable as such links have been, the very nature of the demands made upon them has resulted in their pure research work being more or less dominated by consultative and proving-house work. They have therefore only partially fulfilled those functions which should be covered by the separately co-ordinated and jointly correlated work of our universities and our industrial research laboratories.

Now let us review the reasons for the reluctance of industry to link up with science in the past.

Until comparatively recent times practice and theory have been estranged in most spheres of industry. Between the scientist and the manufacturer there was a great gulf fixed. I have already alluded to the aloofness and lack of sympathy of the scientist towards industry, and having regard to the unscientific basis of the older branches of industry who shall say that his attitude was wrong? At the same time the manufacturer's veneration of trade secrets, his native conservatism, and his distrust of anything scientific tended to double-bar the door. It is only fair to recollect, however, that the manufacturer was hampered by the ignorant prejudice and suspicious attitude of his own workpeople. The spread of education has of course relieved this situation to a very great extent, but I know of some dark corners of industry to-day which the manufacturer dare not disturb.

Generally, however, it may be said that the chief hindrance to the co-operation of science with industry has been attributable to the lack of scientific knowledge on the part of the manufacturer. Consequently it was in a narrow and diffident spirit that industry approached science. As a matter of fact, in the early days the advances towards co-operation usually came from the other direction and were often received by industry with suspicion. In consequence of this attitude, industry as a rule got no more than it deserved. Science had to be gaudily arrayed to render itself attractive to industry, and on the other hand the prospect of a short cut to affluence attracted the scientific *demi-monde* whose main object became the extraction of as much gold as possible before the inevitable day of reckoning arrived. In common fairness it must be said that these mountebanks were not often of British origin. As in other spheres, our national code of morality puts us on a higher plane in science than our antagonists and competitors.

Integrity in science and soundness in the methods of its application to industry are perhaps even more essential than in commerce. Just as the soundness of civilization depends on the assumption that men speak the truth, so the soundness of industry depends on every detail thereof being based on scientific fact.

Happily during the past 20 years or so, owing to the general advance of scientific education, the manufacturer has gradually realized that the function of science was not merely to give occasional assistance, and that the requirements of progress demanded the services of trained technologists who could live and grow up with him.

In spite of diffidence on the part of the manufacturer fully to utilize their services, these technological pioneers have in the interim steadily prepared him for the reception of ideas of closer collaboration between scientific research and industry. They have also prepared much ground for exploration by the pure scientist, and in turn have approached the borderland between science and industry and have been enabled to advance in the light of pure science along various lines of industrial research.

The manufacturer, as shown by the readiness of his associations to co-operate in all matters relating to education and research, is now prepared to take his place in the general scheme of advance. When the necessary fiscal, legal, administrative, and economic reforms which bear on the commercial side of his enterprises are in a fair way to become accomplished, and the factors of education and research have been adjusted to supply him with the scientific assistance he needs, we may rely upon him to contribute his due share in the national effort.

And now in order to give due emphasis to that necessity which I have described as the greatest of all—the necessity for co-ordination of effort and correlation of the results thereof—let us take a bird's-eye view of the ground we have traversed.

We have seen how the national awakening due to the lessons of the war has tended to quicken our normal slow progress and modify our conservative outlook; how it has stimulated national interest in all questions relating to industry; and how this stimulus has in turn led to universal preparation in all directions for the resumption of that position of industrial supremacy, which, for various reasons, we were in danger of losing.

We have touched on a few of the more obviously necessary reforms that have a bearing on those sections of industry with which we as engineers having wide interests are chiefly concerned.

We have surveyed the industrial field and have reviewed the disposition and strength of our fighting forces.

In this survey we have noted the gulf between science and industry, we have seen differences in its magnitude in different industries and in various parts of a given industry, and we have observed the various structures by which the gulf is spanned in its different parts—fairly solid bridges in some cases, mere tight-ropes in others.

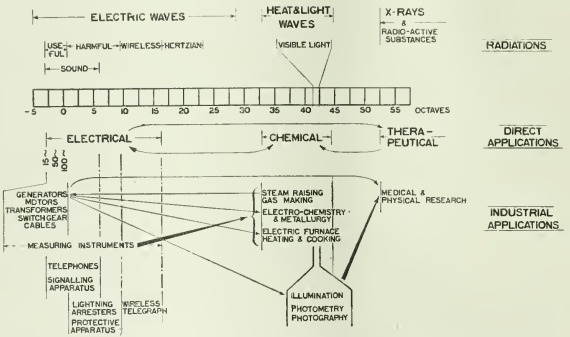
Again on either side of the gulf we have seen gaps or creeks, sharply dividing the various branches of science on the one side, and on the other constituting a barrier between industries.

The Imperial Parliament must lead the way, supported by the Government departments, the educational authorities, the scientific societies, and professional bodies.

The industrial associations and federations and commercial institutions must contribute their influence and resources; the attitude of the individual manufacturers and their managerial staffs must be cordially appreciative; the industrial rank and file must be trained to be helpful, adaptable, and progressive, and the sympathy of the general public must be enlisted. Only thus shall we secure the necessary concerted effort.

In order fully to realize the paramount necessity for correlation of results it is essential that we should appreciate the inter-relation of the component factors, not only between the scientific and industrial fields but between various parts of each of these fields.

I have prepared a rough diagram to illustrate this.



It is abundantly clear that much reclaiming, diverting, and bridging remains to be accomplished.

In our review of the forces at our disposal for this work, we have seen that the sphere of each grade of leader—the research men—on both sides of the gulf is more or less restricted, and have noted the reasons for this comparative segregation. We have seen that they require to be reinforced in numbers, and educated and trained by broader, sounder, and more efficient methods than heretofore.

We have noted that the conditions which have to be faced in the future demand that the best men shall be attracted to these important spheres of action by adequate recognition and reward of their scientific attainments and industrial achievements.

Lastly we have, I hope, appreciated that in order to take full advantage of the new national ideals which are forming, in order that we may accomplish the necessary reforms and efficiently use the forces at our disposal, we require the combined and co-operative support, the co-ordinated effort, and the concerted action of every section of the community.

It is based on the conception that every form of energy may be considered as a form of radiation. Let me here say that this conception is mainly true and capable of proof, but whether one can accept it in its entirety—for instance in the case of radioactive substances—is of no moment for my purpose of illustration.

The diagram consists of a scale in octaves representing the entire known range of radiations. The zero of the scale corresponds to the middle C on the piano. The frequencies represented by the scale range from the 15-period alternating current—with a wave length of 12,500 miles—to the 3×10^{18} frequency of X-rays corresponding to a wave length of 0·00000039 inch.

For the benefit of those unacquainted with our English measures, I would say that these wave lengths correspond to 20,000 kilometres and 0·000001 centimetre respectively.

Above the scale is indicated the branches of physical science with which various parts of the scale are identified. Below are shown, first, the broad fields of application of the phenomena corresponding to given parts of the range; and secondly a number of instances

(which might of course be extended considerably) of industries in each field of application.

In passing let us note where the research men to whom I have referred come in. The whole range of the part above the scale concerns the physicist, although the scope is so enormous that the individual physicist usually concentrates on a portion only. He elucidates the laws and investigates the nature of radiations. Although there is no definite dividing line between the physicist and the pure scientist we may take it that the latter generally deals with phenomena and manifestations of effects. He often specializes to even a greater degree than the physicist, and his sphere of operation often extends, as we have seen, into the industrial field below the scale. The work of both is dependent on the exact mathematical sciences and on experimental proof.

The technologist usually specializes in part of a given section of the industrial field. His work and aims are based on the explorations of the physicist and the systematized knowledge rendered available by the pure scientist. The technical results of his achievements are tempered and circumscribed by commercial considerations, the limitations of materials, the scientific status of his particular industry, and the general state of preparedness of the industrial world to receive the results of his labours.

From a first glance at the diagram as a whole it would appear that the electrical technologist is chiefly concerned with the lower frequencies represented by electrical waves, and that the chemical technologist is more intimately interested in the higher range represented by heat and light waves; but if we look at the lower part in detail we begin to realize some relationships, a few of which are indicated by arrows. Some of these are obvious—many more will, I have no doubt, readily occur to members' minds. For instance, we see a direct connection—through processes of conversion—between the lower frequencies of useful electric waves and the higher frequencies of heat, light, and X-rays; conversely we see direct connection between the higher range of frequencies representing purely chemical phenomena and the lower electrical range, through the familiar voltaic and electrolytic phenomena. As an example of less obvious relationship, I would remind members of the profound bearing which the exceedingly high frequencies represented by X-rays and radioactive substances has been shown to have on the chemical range. The researches of the physicists in this region of highest known frequencies have not only shed light on atomic and molecular structure and proved the Periodic Law—enabling forecasts of undiscovered elements and their properties to be made—but have also explained many phenomena of great importance in industrial chemical processes, such as surface tension, miscibility, passivity, and catalytic action. Other possibilities might be pointed out; but I need only mention one to bring home to electrical engineers the tremendous and far-reaching importance of them. I refer to the possibility—remote perhaps at the moment but undoubtedly a possibility—of determining the fundamental differences between conducting and non-conducting and between magnetic and non-magnetic properties. By comparison, all our previous work on the materials we employ and the processes we use becomes almost empirical in character, and our designs and inventions mere glorified workshop recipes.

With this broad view of inter-relations before us the extreme importance of correlation of results seems to me to be amply emphasized.

I have already pointed out how we as an Institution have a peculiarly intimate interest in the linking up of science and industry and how the composition of our membership and our general functions naturally militate to that end.

I have shown that the science with which our profession is connected is interlinked with all other branches of science, and it is unnecessary to remind members that the industry which is based on that science links up—in its limitless ramifications and applications—with almost every other industry.

I have also pointed out how all classes of the community with varying degrees of comprehension and introspection are regarding this alliance of science and industry as one of the greatest factors in our industrial mobilization, and basing their faith in the future of our Empire thereon.

As industrial citizens, as electrical engineers, as educationalists, as employers, and as advisers we can do much to further the reforms and fulfil the necessities to which I have referred in this Address.

As members of a great Institution let us by giving it our loyal and enthusiastic support ensure that its potentialities and its position in the affairs of the Empire are wisely and efficiently utilized to assist in placing our industrial structure on an unassailable foundation.

SCOTTISH LOCAL SECTION: CHAIRMAN'S ADDRESS.

By Archibald Page, Member.

(*Address delivered* 13 *November*, 1917.)

The whole question of the supply of electric power in the United Kingdom is at present being considered by a Committee appointed by the Board of Trade. This indicates that big changes are in front of us and provides me with the text of my Address. It is not my intention to discuss the controversial aspects of the question or to put forward any scheme for the carrying out of the Committee's conclusions. I propose briefly to consider the general position; to say something as to what has been done up to the present in Scotland, particularly in the Western counties; and to indicate some of the future possibilities.

It is acknowledged that the present multiplicity of power stations—some of them very small—is inefficient; further, that a cheap and adequate supply of electricity should be made available so as to enable British manufacturers to compete successfully in the world's markets. Whatever form the organization created to bring this about may take, all existing artificial boundaries must be ignored or swept away, so that power stations, whether they are of the super type or not, and also irrespective of ownership, shall feed into a common system of mains. The consequent obtaining of the full benefit of the diversity factor on the various classes of load is of the utmost importance, from the point of view both of working expenses and of capital charges.

A great step in advance could be made if a thorough investigation were carried out with the object of settling what is the best scheme for Scotland, especially for the industrial districts. This involves getting all the presently conflicting interests merged in such a way as to ensure the energetic carrying out of whatever process of reform is decided on. We do not want bureaucratic methods, with their paralysing effect on initiative, and no change should be made which cannot be justified as contributing to the cheapening of supply; on the other hand, no vested interest should be allowed to stand in the way of desirable and practicable improvement.

Electricity Supply in Scotland.

There are 46 concerns—20 municipal and 26 company owned. A fair proportion of these distribute in several towns and districts. Electricity is thus available to a large percentage of the population. The capital invested is approximately £9,000,000, the plant capacity at the end of 1916 being 221,000 kw. (£47 per kw.), while the actual load taken as the sum of the consumer's maximum demands was 263,000 h.p. The maximum load on the feeders was 206,000 h.p., showing a diversity factor of 78 per cent. In addition to this, 219,000 h.p. is generated in privately owned electrical plants, while direct driving by steam and gas engines accounts for 637,000 h.p. The total under these three heads is 1,119,000 h.p.

It is only within the last 12 years that the electricity supply authorities have seriously tackled the power problem. In that short time they have taken over one-fourth of the total existing load, and it is the exception to find the management of new works for industrial processes putting down power plant of their own for the generation of electrical energy. The growth of output from power stations giving a public service is very much greater now than it was a few years ago. This is shown in Fig. 1, which gives the number of

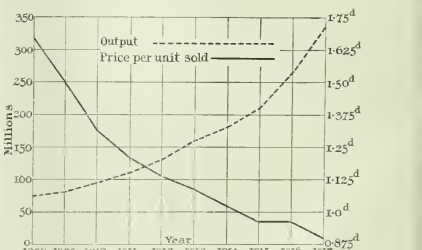


Fig. 1.—Number of units sold within a radius of 25 miles of Glasgow, and average price per unit.

units sold within a radius of 25 miles of Glasgow over a period of 10 years. With this increase in output, and probably accounting for it in large measure, has come a marked reduction in the average selling price per unit, which is now 46 per cent less than it was in 1908. This satisfactory result has accompanied maintenance of and in some cases a marked improvement in the return on the capital expenditure.

It is impossible to dissociate the consolidation of the existing interests and the probable erection of super power stations, also the price of coal, from the following factors which make for the continuation of the slope in the line of average price per unit in Fig. 1, and with the statement of these limitations, we can proceed to examine them.

(1) The Efficiency of the Transformation from Coal to Electricity.

The thermal efficiency (coal to units sold) of the 19 municipal and company-owned generating stations in the area 25 miles around and including Glasgow during the last financial year was only 8·6 per cent. Some authorities claim that an overall efficiency of 17 per cent can now be attained on large systems, and while I see no reason to doubt that such will prove to be the case, it is sufficiently encouraging to know that an efficiency of 15 per cent, which means 22·7 therms per watt-hour delivered at consumers' terminals, is assured in our own district in the event of the existing output being generated in up-to-date stations. This makes ample allowance for distribution and stand-by losses, and represents a saving of 43 per cent in the coal bill, which at present prices would amount to £181,000. When certain projected schemes involving the use of large units in river-side stations are more fully developed, a considerable improvement will take place.

I do not mean to convey that what was done in past years was wrong, either on the engineering or business side. It has been a gradual process of evolution from the old days of small Willans engines and low-voltage continuous-current distribution; but we are now on the threshold of a great development, and there is no doubt that if we effect the improvement in thermal efficiency outlined above, the cheapening of electricity produced by public supply authorities will continue, bringing in its train enormously increased outputs and further reductions in price. The possibilities thus presented to us are largely due to the introduction and continued improvement in the design of the turbo-alternator. The first machine of this type in Scotland of which I have any record was installed at Port Dundas station in 1904, and when running at full load the thermal efficiency, without deducting power for auxiliaries and with good boiler-house conditions, worked out at 11·8 per cent. The next well-defined stage took place in 1908 and involved doubling the speed; this gave an efficiency of 13·9 per cent. This was followed in 1912 by machines of twice the size of the original turbine, the overall efficiency being 15·5 per cent. In the present year there has been a still more marked increase in the size. Orders for three 15,000–18,000 kw. sets to be installed locally have been placed. It is expected that this plant will be in full commercial use before next winter. The guaranteed efficiency at full load has again advanced, this time to 21·3 per cent. The later developments have been accompanied by an increase in steam pressure and temperature, also in vacuum. Twenty years ago a boiler pressure of 200 lb. per sq. in. with the steam superheated to 500° F. was accepted as good practice in connection with power stations then being built, and until quite recently the position had not altered, except that 50° F. had been added to the steam temperature. The large turbines just referred to are to be supplied with steam at 250 lb. per sq. in. superheated to 650° F.

Now that we have passed the stage which was imposed on us largely by the limitation of cast iron as used for turbine bodies and valve chests, it will probably not be long ere we reach much higher pressures and temperatures. The boiler and turbine makers say they see no insuperable difficulties, and if the trouble with fittings and joints can be overcome the available heat drop per pound of steam will be materially increased.

It is impossible to get the best results in a power station unless the highest vacuum is aimed at and the number of heat units per pound of steam discharged to the condenser reduced to a minimum. For that reason I hold the view that all stations working on low vacuum and within reasonable distance of but not actually situated on the seaboard or on a river, ought to have no more plant installed in them but as soon as possible should be shut down. I am aware that in populous inland districts, particularly in England, it would be difficult to comply with this requirement, but if we deal with the problem on national lines, as we ought to do, long-distance distribution will have to be faced.

The flow of water in the summer months on the non-tidal portion of the Clyde in the vicinity of Glasgow and near the Lanarkshire coal-fields, and at a point where the full benefit of all the tributaries is obtained, can only be safely taken as 22,000,000 gallons per hour. The maximum load a super power station so situated would therefore be capable of handling would be 250,000 kw. and to allow of this the whole of the water in the river would require to pass through the condensers. The temperature of the water would be raised by about 12° F. The temperature due to a vacuum of 97 per cent is 75·8° F., giving little margin for higher inlet temperatures farther down the river. The cooling of the water would depend on atmospheric conditions and there might be little reduction in the temperature at a distance of several miles below the site. We are therefore forced to the conclusion that if more than 250,000 kw. is required, another station would have to be constructed on the tidal part of the river. This means dearer coal, which might to some extent be compensated for by lower distribution losses.

There is comparatively little scope for improvement in the efficiency of boiler-house plant as far as the manufacturer is concerned.

There has always been a chronic shortage of boiler capacity in electricity generating stations, and nothing I know of can be more detrimental to the work of the staff than this: they are continually harassed with the difficulty of keeping up the steam pressure, boilers and economizers cannot be laid off for cleaning as often as they should be, and the boilers in commission, being forced beyond their capacity, work inefficiently. Stoker troubles are also multiplied.

One of the greatest difficulties to deal with, and one which has a disastrous effect on economy, is the sudden call for steam when a thunderstorm breaks over a large city in summer, or on the sudden descent of fog. The winter lighting load is suddenly thrown on the power stations, and as a considerable proportion of the boilers are out of commission for overhaul or to save excessive stand-by losses, if the darkness

lasts for any time a serious situation arises. An analysis of the yearly output of several concerns in this district shows that the units sold for lighting vary from 7 per cent to 15 per cent of the total output. The maximum load due to the lighting consumers may even now, however, be 40 per cent of the total, and because of this I have known the sustained load on a single station increase from 15,000 to 23,000 kw. in five minutes practically without warning.

Linking up existing stations, increasing the output until the lighting peak becomes a very small proportion of the total, and increasing the diversity factor by generating the power required by a large district in one or two super stations will automatically stop what has been a perfect nightmare for many years to central station engineers in large cities.

As a boiler-house efficiency of 70 per cent may be taken as the average for the larger generating stations of to-day, it is obvious there is too great a difference between that and the highest possible figure of, say, 87 per cent. After allowing for stand-by losses and power to drive the auxiliaries, it is possible to get 80 per cent efficiency continuously out of a well-designed plant run by a staff who know their business thoroughly. The well-trained heat engineer, who must be a chemist as well as an engineer, is an indispensable member of such a staff.

These remarks on the possibility of effecting an improvement in the boiler-house would not be complete without a reference to the carbonization and gasification of coal in connection with the production of electricity On the simple question of converting the largest possible proportion of the heat units in the coal into steam, we are following the correct procedure in burning the coal under the boilers, but in doing so we are destroying otherwise useful and valuable constituents to get heat. Some of our critics pronounce it wanton destruction, but unfortunately the balance sheet shows that it does not pay us to preserve the ammonia, oils, and tars following any of the processes which are open to us at present.

The Fuel Research Board, however, are about to carry out a thorough investigation of the subject at a research station to be erected at the East Greenwich gas works of the South Metropolitan Gas Company.

Meantime the call for more and more electricity is insistent, and the only course for supply authorities is to build the new stations arranged for dealing with the raw material in the old way, and, if possible, to choose sites with a sufficient margin of spare ground on which to erect gas producers and recovery plant if and when such procedure is justified.

Transmission over long distances at high pressures presents no insuperable engineering difficulties. In a good many quarters it seems to be assumed that if from the coal conservation point of view it can be shown that the load of a district ought to be supplied from one, or at most two centres, the provision of the necessary cables and the losses thereon can be looked upon as entirely subsidiary, and with little or no bearing on the scheme as a whole when compared with existing methods. It is argued that if we had it all to do over again we would arrange to distribute power say up to 500,000 kw. from one point. In distributing this amount of power there would be no need to worry much about line losses and in any case they would be counterbalanced by the increased diversity of the load; further, that too many mistakes have been made already, and unless the long view is taken now we will find ourselves as the years go on in a more hopeless muddle than ever. There is a great deal to be said for all this, but unfortunately we have very little experience of the cost of transmitting large amounts of power over long distances in this country. It is easy to show by calculation that it does not pay under certain circumstances. It is obvious that there are rocks ahead, particularly in the transition stage, and careful piloting will be required.

The distribution losses on fairly extensive systems at present amount to about 10 per cent of the units generated, but the tendency will be for these losses to increase: and no assistance from the cable system can be looked for in the search for improved thermal efficiency.

The use of alternating-current apparatus should be extended as far as possible for general purposes. Practically all electricity is generated by turbo-alternators and the conversion from alternating to continuous current has a bad effect on the overall efficiency. There is no longer any real justification for it on the score of adaptability, and it seriously affects the reliability of the supply.

(2) Use of Waste Heat and Water Power.

There are two main sources of waste heat in the form of gas, i.e. from blast furnaces and from coke ovens. Other sources of waste heat which may be mentioned are iron puddling furnaces, forges, and reheating ovens, but these are not of sufficient importance to be taken into consideration. As the quantity of exhaust steam from non-condensing engines will gradually dwindle with the adoption of electrically-driven rolling mills and winding engines, no great assistance is likely to be got from this quarter. No combination of non-condensing engine and exhaust steam turbine of the sizes used in public works approaches the thermal efficiency of an up-to-date power station. It would therefore appear to be wrong policy for public supply authorities to install exhaust steam turbines, unless under some special business agreement, even although the steam were available in sufficiently large quantity and could be bought at a very cheap price.

In 1916 the average number of blast furnaces in Scotland was 74, these being mainly in the West. These blast furnaces produced 1,144,768 tons of pig iron for the year. Assume that 1 ton of coke is used per ton of iron and that 34 per cent of the total heat is carried away in the waste gases after deducting the necessary heat for the hot blast. Having made ample provision for general works purposes there is still 25 per cent left which, converted into electricity at the comparatively low thermal efficiency of 10 per cent represents 207,000,000 units. As a matter of fact, nearly 2 tons of a mixture one-fifth coke and four-

fifths splint coal is used per ton of iron in the Scottish blast furnaces, and this greatly increases the heat which could be utilized, but for the purposes of an estimate it has been considered better to base on the more general figure of 1 ton. At present most of this power is literally going to waste.

The expansion of the electricity-supply business provides the means of stopping this great economic waste, and although owing to the scattered location of the furnaces a number of generating stations would be required, the plant in such stations would be running on a very high load factor. A common distribution system for the whole central area of Scotland,

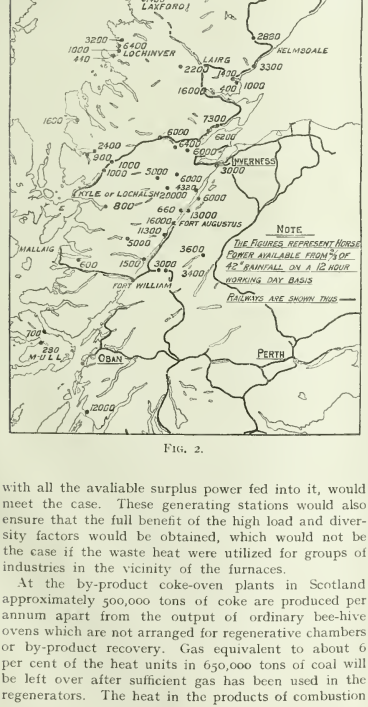


FIG. 2.

with all the available surplus power fed into it, would meet the case. These generating stations would also ensure that the full benefit of the high load and diversity factors would be obtained, which would not be the case if the waste heat were utilized for groups of industries in the vicinity of the furnaces.

At the by-product coke-oven plants in Scotland approximately 500,000 tons of coke are produced per annum apart from the output of ordinary bee-hive ovens which are not arranged for regenerative chambers or by-product recovery. Gas equivalent to about 6 per cent of the heat units in 650,000 tons of coal will be left over after sufficient gas has been used in the regenerators. The heat in the products of combustion discharged from the regenerators will add another 4 per cent, so that altogether there is 10 per cent of the total heat in the coal available for steam-raising purposes. This works out to 50,000,000 units. If all the coke was produced at one centre there might be something in it, but as the plants are in four counties the surplus at each place is comparatively small and consequently does not fit very well into the scheme we are considering.

With regard to water power, in the North and North-West of Scotland there is a very considerable amount available. Professor Forbes, F.R.S., has put forward the figure of 1,000,000 h.p. as his estimate of the possibilities in Scotland; but we ought to have full and properly worked out data in connection with such an apparently important source of energy, especially now that coal conservation has come to be looked upon as a national matter of the highest importance.

Through the courtesy of Mr. A. Newlands, Chief Engineer to the Highland Railway Company, who has made an exhaustive study of this problem, I am enabled to include a map (Fig. 2) giving information of the approximate amount of water power available in certain parts of Scotland—mainly in the vicinity of the Caledonian Canal. It is not claimed that the 45 localities indicated are by any means comprehensive, and yet the aggregate is 215,000 h.p., which, on a conservative estimate, based on a rainfall of 42 inches per annum, could be maintained if the load factor were 50 per cent. Ample allowance is made for loss by evaporation and absorption in the ground, also for compensation water.

Assuming a total cost per kilowatt of £40, including transmission lines, etc., and that the load factor would be kept high, water power may be regarded as another cheapening factor in the production of electricity in Scotland. The ideal arrangement would be to have water power stations feeding on to national trunk lines, and thus to encourage the removal of some of the industries from the cities and the starting of new industries in the vicinity of these power stations.

Much depends on the attitude of those who own the water rights, but nothing should be allowed to retard this legitimate expansion of the resources of the country.

(3) Increase of Output.

This goes on automatically, and that we are not anywhere near to saturation point is shown by the fact that only 24 per cent of the power used in Scotland is generated by electricity-supply concerns. There is thus a wide field still to work on, and even further scope for extension will result from intensification.

Chicago and district, with its population of 2½ millions, uses 480 units *per capita* supplied by the Chicago Edison Company: whereas in the West of Scotland, where the population is about the same, the units *per capita* work out at only 160.

This is a startling difference which is to some extent accounted for by the fact that railway electrification has gone much farther in America than it has here. There is also far less gas used in domestic premises in

America. Even a rough survey of the facts shows how much has yet to be done, not only in our district, but all over Great Britain.

Turning to the newer uses of electricity, the list includes railway electrification, metallurgical processes, chemical processes, and agriculture.

Railway electrification.—This is to a large extent a question of cheap electricity. Steam locomotive engineers are constantly effecting improvements in design, but the efficiency of the transformation of the heat units in the coal into mechanical energy at the drawbar is still much in favour of the electrical scheme, particularly if the electricity were produced in a large and efficient power station. Railway companies do not want to generate the electricity they will require, as the lower the capital cost of electrification the more it appeals to them; and if the working costs are to be kept down electricity must be produced on a large scale in stations where the full benefit of the diversity between all classes of load is obtained. The consumption of coal for locomotive purposes on the Scottish railways last year was 2,187,000 tons. This would be reduced at least 40 per cent if the railways were electrified, and this means from the electrical standpoint an output at 10 per cent efficiency of 1,000,000,000 units without regard to increased traffic.

Metallurgical processes.—The manufacture of steel in the electric furnace is rapidly increasing, and although there are only four such furnaces in commission in Scotland, many are on order. In 1916 the production of electrically-made steel was 50,000 tons for the whole of the country, while the number of funaces built or under construction was 91—an increase of 46 over 1915. The size as well as the number of the units is increasing, and 20-ton electric furnaces are now in regular use.

A direct comparison with the cost of the older methods of producing heat for the melting and refining of the charge will, as has so often been the case in other applications of electricity, apparently show that there is no justification for the change. The incidental advantages are, however, so great that the future holds very bright prospects from the electricity-supply point of view. These advantages are:—

(*a*) Perfect control of temperature, which can be carried higher than by any other means.
(*b*) The temperature is obtained without interfering chemically with the process of refining.
(*c*) High-class steel can be produced from low-grade scrap. This will go a long way to pay for electricity.
(*d*) The quantity of ferro-alloys required is considerably reduced.
(*e*) The refining process can be carried to any degree required.
(*f*) Smaller furnaces involving lighter structures, cranes and other equipment, will give the same daily output owing to the more rapid melting of the charge, and also because the process can be repeated in a regular way.
(*g*) Refractory material and labour costs are lower. This is offset by cost of electrodes.

There is an impression that electric furnaces can only be used profitably in the making of higher grade and special steels, but this is erroneous, as experience will show.

It is possible to arrange that the load on the stations will be of an "off-peak" character, resulting in greatly improved load factors. Had the 1,750,000 tons of steel produced in Scotland last year been made in electric furnaces, it would have meant a consumption of approximately 1,100,000,000, units. This opens up a wide question, but it suffices to show that here again there is plenty of scope for increasing the output of electricity.

Electric furnaces are also being used in the manufacture of ferro-alloys and abrasive materials, such as allundum, by the fusing of bauxite. This does not by any means exhaust the list of uses, but I make special mention of these as plants are being erected locally which, when complete, will absorb a considerable amount of power. These furnaces are going to be of great assistance in the iron foundry trades, as it will be possible to cast at frequent intervals during the day, thus saving floor-space and reducing materially the cost of the general equipment.

Chemical processes.—These include the fixation of atmospheric nitrogen by special forms of the electric arc and the production of calcium carbide. These two processes alone will utilize an enormous amount of energy, and many other electrochemical processes are being developed.

Agricultural development.—Recent experience has given a great stimulus to this, our oldest and largest industry. Farmers are always eager to get a supply if electricity mains are in their vicinity, and this benefits the supply authorities when wayleaves have to be negotiated. If the amount of land under crops is to be materially increased many operations which are now carried out by manual labour will require to be done by machinery. The experiments which have been conducted in connection with electro-culture show that the yield from areas so treated is considerably in excess of the normal. With standardized apparatus of robust construction made available agricultural development along these lines will proceed rapidly.

The Incorporated Municipal Electrical Association have taken the matter up and have appointed a special Committee who will invite representatives of all the interests concerned to join them, so that the movement towards providing the necessary information and electrical facilities is well started. The Board of Agriculture and the Conjoint Board of Scientific Societies are also carrying out investigations, and if an energetic and progressive policy is followed, good results are sure to accrue.

I will only deal with a few of the other miscellaneous applications of electrical energy.

Satisfactory progress is being maintained in the electric vehicle business. With petrol so scarce and dear the electric vehicle is becoming increasingly popular. The high first cost is still a drawback, and this will not be improved until British makers are in a position to build these vehicles in large numbers.

Owing, in some measure, to the shortage of com-

pressed oxygen for use in the oxy-acetylene method of welding, extended applications of electric welding have been made with marked success, both from the commercial and practical sides. The making of mines and other such equipment for the Navy and Army has been greatly facilitated by this means, and now that extended experience has been gained the scope of electric welding in the sheet-metal trades is sure to expand.

If electric cookers were as readily obtainable as similar gas apparatus, the consumption of electricity in the house would increase even more rapidly than is the case at present. Domestic work nowadays has to be done with the minimum of hired assistance, and clean, handy, labour-saving devices using electricity help in many ways.

It may not be inopportune to refer at this point to the question of power factor. Wattless current is a costly product to all concerned, and a great deal more care should be exercised by power users in seeing that their transformers and motors are installed and used with some appreciation of the factors involved. Motors as a rule are run much under full load, sub-division not being carried far enough. Transformers are treated in the same way and left on the mains when they should be switched off. Apparatus generally is bought without power factor being mentioned, with the result that the capacity of the generating plant and mains is curtailed, and the cost of the service therefore higher than it should be. It looks as if the only way to effect a much desired improvement is to charge for electricity so much per kilovolt-ampere-hour instead of per kilowatt-hour. This method has actually been adopted in the South.

(4) Standardization.

Much good work has been done by the British Engineering Standards Committee, and the active co-operation of American electrical interests which is now taking place (Mr. H. M. Hobart having come over from the States for this purpose) will be of material assistance. Report No. 72, a copy of which should be in every electrical engineer's office, is a most valuable contribution, and the more work there is done in this direction in conjunction with the movement towards bigger plant, the cheaper will the cost per kilowatt of plant installed become.

The problem of supply in bulk and interlinking is being much complicated by the fact that the periodicity of the alternating-current systems throughout Scotland are not uniform. Fifty periods will probably be adopted as the standard periodicity for the United Kingdom. There are 13 concerns in Scotland generating alternating current on a fairly large scale. Three of these have adopted 25 periods and have a plant capacity of 115,000 kw., which is being rapidly extended, while the other 10, with the exception of one at 60 periods, have adopted 50 periods. Their plant capacity, however, only aggregates 60,000 kw. When the time comes for settling the system for the super power stations from which the whole of Scotland will eventually get its supply, the task will be no easy one, as so many conflicting factors will require to be taken into account. It is hoped that those who are given this problem to solve will take the long view, as, whatever be the decision arrived at, it will be final and irrevocable.

(5) Taxation.

One of the penalties which has been imposed on electric supply undertakings, as a consequence of having been granted a monopoly in connection with the supply of electricity in given areas, is the payment of very heavy taxation for local purposes, in comparison with the amount debited against other large trading concerns.

It has always been maintained in our district, and I think rightly so, that the general body of rate-payers should not benefit at the expense of the users of electricity. The system of valuation—known as the revenue principle—applied to public undertakings is inequitable and should be altered so that the incidence may be less unfair.

BIRMINGHAM LOCAL SECTION: CHAIRMAN'S ADDRESS.

By Sydney T. Allen, Member.

(Address delivered 14 November, 1917.)

It is not my intention to read a technical paper but to make a few remarks bearing upon matters in which many of us are specially interested at the present extraordinary time in the history of the Institution, occasioned by what was called the "European War," but which can now be described as the "World War."

We shall probably be experiencing during the coming winter the most strenuous time, as far as those engaged on the industrial side of the applications of electricity are concerned, that has been experienced during any period of the war. I therefore feel it is advisable that we should make these meetings as far as possible a real relaxation from our other duties.

We might perhaps treat our meetings during the war in a less formal and serious manner, at the same time conforming entirely with the rules of the Institution, with which we are all proud to be associated.

I think the strict formality of some meetings in the past has prevented a large number of the younger members from joining in the discussions, and it seems to me to be a pity if this formality, or shall I say want of sympathetic understanding between members, defeats in any way the objects of these meetings.

One cannot help noticing what a different atmosphere exists at the informal meetings which are held after the formal meetings, and how animated is the discussion which often arises on the subject of the papers, by members who seldom if ever take any part in the discussions at the formal meetings. I think this prevails to a great extent at the meetings at other centres, and it is a great loss to the Institution if many of the younger and other members who do not take part in the discussions cannot be persuaded to do so. Such members form by far the great majority and are often by their knowledge and practical experience well fitted to further the principal objects of the Institution.

I mention this in my Address at the commencement of the session, and I appeal to all members to contribute something, however small, either in writing or personally at the meetings, to the discussions on those papers with the subject of which they are acquainted in their everyday life. Often most valuable and instructive remarks come from members who, although they may not be gifted as public speakers, for which they are wholeheartedly excused, are able to add items of great interest from their own practical experience, not only to their friends in this particular local section, but also to the electrical community throughout the world. These meetings are practically the only opportunities which we, as members, have for interchanging ideas and knowledge.

There is no branch of science in which developments are taking place more rapidly than that in which we are all interested, and many of those developments are far-reaching and of great importance to the future industrial position of this country. This is why I have laid special stress on the importance of a very free intercourse between us at the present time.

Whilst dealing with this matter it is very gratifying to be able to note how much closer is the intercourse and relationship between this Institution, which in its earlier life restricted its operations and considerations more to electrical science from a theoretical point of view, and other Institutions and Associations which deal with the applications of that science more from their industrial and commercial aspects.

The fact is being realized more and more at the present time that there should be no barrier between the theorist and the practical man. The former should be encouraged always to have before him the necessities and difficulties in connection with practical applications: the practical man on the other hand should always realize that the days of success by "hit and miss" methods are gone, and that in the great competition of nations it is of vital importance to the future welfare of all sections of the electrical industry that the scientific and theoretical side of all matters connected with them should have a prominent place and a more prominent place than it has in the past.

The war has awaked this country as to its industrial position as perhaps nothing else could. We so easily recognize things now to which we were blind before.

In the past we have, as a nation, been slow to recognize the possibilities of some of the applications of electricity as far as manufacture in this country was concerned. Absolute necessity, with perhaps Government assistance, has forced manufacturers to produce things which were previously mainly made outside this country; and this same compulsion has opened the eyes of manufacturers to the enormous possibilities in the use of electricity and of scientifically designed apparatus and machinery.

Several instances might be cited of manufacturers who have, by means of modern labour-saving plant, surprised themselves in the enormous and successful increase they have been able to make in their output with the same works and staff, and, what is of greater importance, in the improvements they have been able to effect in the cost of production, calculating the cost of raw material and labour on a pre-war basis.

A large manufacturer told me soon after the war began that he was requested to make an article which had previously been imported mainly from Germany and which he had considered for years he could not produce to compete with the imported article. After commencing to manufacture this article he found that he could well produce it at a price, after calculating on a basis of pre-war costs, cheaper than the same article could be imported previous to the war, and this with his original plant, etc.

This brings out another point which I wish to touch upon, and that is the evidence which the war has produced of the want of confidence of a great number of British manufacturers in the past in their own abilities. This want of confidence was not confined to the manufacturers themselves, but unfortunately to a large extent to others who were able by their influence and financial assistance to further the great progress in the electrical industry which was bound to continue. The benefits derived from this progress if not taken advantage of by us in Great Britain, would surely be worked to benefit other countries.

Of course restrictive legislation and other causes greatly discouraged advancement of electrical development in the past; but as the co-operation and combined action of such Institutions as ours, representing as it does the greater number of scientifically and technically trained and experienced electrical men in the country, has already done an enormous amount to influence the ruling powers to decide on reconstructing the legislation on electrical matters, so we in the future, with the great lessons of the past before us and with a much greater confidence in ourselves, should by united efforts and mutual support accomplish those things which will make and keep Great Britain first in the world in the great advancements that we cannot help but see ahead of us.

I am sure that this Local Section will fully awaken to the realization of the necessity of greater activities. Such activities do more than express opinions or pious hopes such as I may refer to in this Address, and will help forward the work that must be undertaken to bring about those results which are so necessary.

There are many ways in which we might act to help to bring about these results.

First of all we must realize that our work is of national importance. We must endeavour to encourage all members to have sufficient self-confidence to express their views without hesitation and to hold broad-minded views on all things as long as possible. We must not hesitate to express those views and describe our experiences when occasion arises.

I think, further, that we should consider it wrong to withhold information when its publication might benefit the nation. It is almost as wrong for a person to withhold such information which he does not intend to make certain use of, as for a person to hold patent rights in connection with useful practical applications which he does not intend to put into practical operation.

I think that real efforts should be made by encouragement and live inducements to attract a much larger Student membership. It is to the student of the present day that the country must look for the great and important work of the future, and I think this Institution has a definite responsibility to see that it assists forward that part of their Students' education which can only be accomplished through its efforts.

To this end I suggest the formation of a special Students' Section in this area after an interesting and useful programme has been drawn up for them. They might have their own Sub-Committee, and of course special representation on the main Committee. Special meetings for the junior members alone would tend to encourage that practice in discussion which I have previously spoken of as being so badly needed.

There is little doubt as to the desirability of the formation of a central bureau or headquarters for this district, from which information on matters relating to the proceedings and work of the Institution, the Standard Rules and Conditions which it has drawn up, and the work of its various Committees, etc., could be distributed. Some central place is required where members can meet to discuss matters affecting local electrical work and conditions.

I do not suggest a club in connection with the Institution in Birmingham but I cannot help thinking of the enormous local benefits which are often derived from such institutions as the Engineers' Club in Manchester.

It may be that we shall be able to take a much more active part in the work of the local chambers of commerce in the future and be strongly represented on those and similar bodies, and perhaps form separate sections in them. If this be the case it will be more necessary to have some central headquarters.

There may be financial difficulties, but these should be overcome.

It may be said that any radical changes in our operations should be postponed until after the war, but I think it is because of the war that changes and greatly increased activities are necessary.

I am very glad that I have received suggestions from members on this matter, as it tends to prove that the Birmingham Local Section is not behind the other local sections in that progressive spirit which is being displayed in electrical matters throughout the country.

I think that one of the most important matters which should have the consideration of the Institution is the means by which the large new industries lately introduced into this country may be retained after the war. Large developments have taken place in the industrial applications of electricity which had not, on account of extensive and effective foreign competition, been carried out in this country but which in the light of our experiences since the war began and on account of the great necessities occasioned by the war, have received active encouragement.

This development must be further encouraged and systems and methods perfected, so that when the great demands due to the war cease, we may continue in such a condition of economical production that these new industries which have sprung up may

serve as a basis for stronger industrial supremacy afterwards.

I think no better example can be cited than the electro-metallurgical and chemical furnace industries which are being started in this country and in this immediate district. Of course we have had steel and other furnaces in use previous to the war, but the developments in this direction have since increased to an extent far beyond anything expected. Large plants have been and are being put down for the making of high-class steel for the smelting and refining of metals, the making of calcium carbide, phosphorous, arcorundum, aluminium and many other substances requiring electrical energy, in some plants at rates of over 10,000 units per hour.

If we look back afterwards upon the war as having performed some useful service to the industrial position of the country, I hope that we shall be able to instance the forced introduction of these industries together with many others. The mere introduction of certain industries at these abnormal times, when costs do not determine or limit their operation, does not necessarily mean their successful continuation afterwards when the war requirements cease and when the world's demand for the materials produced can again be met from other and competitive sources. It should, however, be our duty to make every effort to retain those industries in a flourishing condition, and this can only be accomplished after great co-operative effort, realizing, as we should do, the enormous benefits we should derive from their continuation.

Vast sums of money are being expended in this country in this one branch of industry which I instance, and let us briefly consider the position in some of its aspects.

The electric furnace work may be split up into two main sections :—

First, the use of those furnaces that are required for work for which the electric furnace is almost alone suitable and without which the industry could hardly exist ; and as examples I would mention the production of aluminium and calcium carbide.

Secondly, those industries in which the electric furnace is still a competitor with fuel furnaces, such as for steel production, zinc smelting, etc.

It does not follow that because, for instance, the electric calcium-carbide furnace has little to fear from competition from any fuel furnace, that it is the furnace which can make headway in this country however many large plants may have been put down owing to the war demands. These plants have been put into operation mainly because of the great difficulty of transport from those countries where such plants existed which had supplied these commodities before, and not because of the comparative costs of production.

These particular furnace plants, which previously supplied the world's markets, obtained their electrical energy from water-power supplies, whereas we are obtaining our energy from coal-burning plant, the costs for electrical energy being generally much higher in consequence. We shall therefore in the future be in the position that we shall have large furnace plants in working order with the employees available for running them with a great deal of experience gained during the war on the working of such plants, but it is unlikely, unless great changes are made in the costs of production and in our internal transit charges and facilities, that we shall be able to compete against the supplies from foreign water-power plant and the low freight charges from those countries who previously had the monopoly of this furnace industry production.

In the case of the other type of electric furnace industries to which I refer, we shall still have also the competition of the fuel furnaces.

The necessary low power price, coupled with easy and cheap internal transport facilities, will be the key to the continuation of not only the particular industry to which I have referred, but also to an enormous bulk of the other industries which have been commenced in this country.

The supply of electricity on a much larger scale and at much cheaper prices must have one of the very first places in the consideration of the country in the near future, and nothing can be of greater importance to the electrical engineers collectively than the devising of means to bring about that important result. The Government has already had such strong representation made to it that it is taking important action ; but there are matters of great issue to be settled which will require the united efforts of all seriously thinking institutions such as ours.

The question of cheap electricity supply has become a national one, and we must look upon it as such. These cheap supplies which are so necessary are mainly dependent upon cheap fuel and a much better use of it, the reduction in the handling and transport of unnecessary material, the production of electricity by means of large units, and its transmission from those large units by extra-high-pressure currents.

These points and many others have already been decided and are obvious, but the best means of bringing them about is what the electrical world is still discussing. There are so many points which will have to be considered from so many important aspects that a considerable time will elapse before any decision upon any definite schemes affecting all the electricity generating centres in the country can be acted upon ; and it is quite uncertain whether any scheme which will be satisfactory for one section of the country will be satisfactory for all the others.

The number of the generating stations in the country must of necessity be reduced, but it does not follow that the positions of the large stations which now exist will be the positions in the future for the fewer generating stations which should supply the country's needs.

Whilst it is a fact that most of our principal centres of industry owe their position to existing collieries in the immediate neighbourhood, it must be remembered that owing to the gradual working out of coal seams in certain districts, and to the exploiting of others in districts farther away, the centres of maximum coal output are altering, so that the main generating stations of to-day which are placed in a satisfactory

position with regard to existing collieries may not be so conveniently placed in the future.

Again the question of internal transport will affect the issue very much indeed. If great changes for the better are effected in this direction no existing costs of transmitting coal will avail in considering the matter.

Coal transmitted under existing conditions might cost twice as much to transmit as it would after the whole system of rail and canal traffic facilities had been re-organized to suit the best needs of the nation as a whole, instead of those of individuals who own them for their own interests.

The question as to whether the coal should be carried to the generating stations or whether the stations should be erected at the collieries depends upon local conditions to a great extent.

The large quantities of water which will be required for condensing purposes will also be an important determining factor.

The valuable by-products which can be obtained from certain coals should be put to their greatest and most important uses, and although it is a somewhat debatable point as to whether the recovery of these by-products on extensive lines would help in any way in directly cheapening electricity supply, the matter will have to be considered on other grounds.

A problem for investigation is whether it would be more economical to produce gas from the coal at the collieries and transmit under pressure to generating stations at places more suitable on account of water and other facilities.

It is to be hoped that no great decisions affecting these matters of national importance will be arrived at without the most thorough and open investigations have been made by all parties interested.

The economies to be obtained from the linking up of different generating stations throughout the country have already received a large amount of consideration. Here again local circumstances must determine the matter. It seems certain, however, that schemes of electrically linking up existing generating stations will precede any great changes in the matter of centralization of electric power supply.

The question of linking up the principal power stations in the Midland area is already being dealt with by a committee appointed for the purpose, and their decisions may soon be made known.

The connecting electrically of, say, two power stations may be arranged to serve three purposes:

First, to improve the efficiency of both stations, arranging the division of the total load between them so that the daily load factor of the running plant may be improved. This would be accomplished by completely shutting down as far as possible all plant which would otherwise be only partly loaded, and by keeping the most economical units at both stations running at their most economical loads.

Secondly, so that the amount of spare plant at both stations may be reduced, thus reducing capital expenditure.

Thirdly, to allow of plant in each station to be shut down during certain week-ends to allow the very necessary cleaning of boilers, flues, etc., and general overhauling to be carried out.

There are many complicated considerations which must be thoroughly thrashed out before any useful decisions can be arrived at.

When such stations are linked up electrically, if this is to be made use of to the best advantage, it will be necessary for such a complete understanding between the managements of the different undertakings that they can be controlled as one undertaking as far as the division of loads between them is concerned. A control board must of necessity be set up representing all the undertakings to decide principally on the extensions and amount of spare plant at the different stations, on the division of the load between them, and on the charges which should be made for the interchange supplies.

It is unfortunate that the conditions due to the war demands have prevented the attainment at present of the principal objects of linking up, owing to the fact that practically all electric power stations are fully loaded with little or no spare plant and are obliged to run their older and less economical plant for long hours daily, tending to reduce considerably economical production. This continual running of nearly all the plant available has also prevented that regular cleaning of boilers, flues, condensers, etc., which is so necessary for economy; and also what is important, the shortness of staff has tended to prevent to some extent that continuous check and control which is so necessary. The temporary labour often employed is much more inexperienced and really calls for extra and not reduced control.

It is generally recognized, however, that schemes of linking up on a smaller scale to allow of individual stations which are fully loaded throughout the week to be either partly or wholly shut down during certain week-ends for the necessary repairs before referred to, should be considered and put into operation, if feasible, as soon as possible.

The electrical linking-up itself must involve a considerable amount of capital expenditure and is complicated owing to the fact that the class of supply from the different generating stations varies considerably; some generate continuous current, and others alternating current differing as to phase, periodicity, and pressure.

There is an important matter bearing upon the present costs of electrical energy and railway and canal traffic to which I should like briefly to refer, and that is the large and increasing amount of incombustible matter being distributed throughout the country with the fuel we are burning. If it ended with the waste of transport it would not be so bad, but unfortunately hundreds of thousands of tons of this useless material under present conditions has to be heated up and mostly fused in the boiler furnaces, entailing large heat losses, dirtier flues, reduced boiler output and inefficient steam production, and then to be transported again away to tips often many miles distant.

The hundreds of thousands of extra tons of this useless material mixed with the fuel is being sold and transported about the country, employing after it

leaves the collieries an enormous amount of extra labour, locking up trucks and canal boats which could be put to some useful purpose, and adding to the already congested condition of things. In the Midlands the overall cost to the user of this incombustible matter must average over £1 per ton, and if the percentage increase of it since before the war be taken as 10 per cent, a modest figure, it will readily be realized what an enormous waste is going on and how this increases the cost of production of electrical energy.

This points to the uselessness, in comparing overall efficiencies, of taking quoted figures of pounds of coal per unit generated at the present time without special care being taken to ascertain the heat values of the coals used.

This extra cost of coal after it has left the collieries must outweigh many times any cost which would be involved by the colliery authorities in improved washing, picking, cleaning, and grading the coal; and if it could be assured that cleaner coal could be guaranteed, a much higher price could be paid for it.

Unfortunately large buyers of coal are unable to determine the source or quality of the coal they purchase at the present time, and it is unlikely that this condition will alter for some time. I think that a great deal of the loss and waste in connection with fuel at the present time could be prevented if a standard coal specification could be agreed and acted upon.

The time at my disposal will not permit me to refer to other matters which might engage our attention during the coming session. Before concluding, however, I should like to refer to a bulletin which I received from New York a few days ago. This particular bulletin was issued by one of the United States new Consulting Boards which have been formed on account of the war, and it deals with the submarine and kindred problems. It is written with the intention of setting out in a concise manner a large amount of information relating to the modern submarine and torpedo as now used. This information is to form a basis for the consideration of the people in the United States on this matter and at the same time an invitation and an encouragement to those people to assist in the devising of means effectually to combat and nullify the power of the German submarine.

It is interesting to note that the Board who issued this bulletin mainly consists of electrical engineers. After reading it carefully through I was struck with one or two important points.

The governing bodies in the United States realize not only the great importance of encouraging the serious thoughts and assistance of the largest number of people on these vital questions, but also that the man who may be at present of little importance to his country may, if encouraged in the right line of thought, be of the greatest service to it. As it is in the United States of importance to co-opt everyone possible in the consideration of these problems, so it is of greater importance for us to encourage and assist as far as possible everyone interested in the electrical industry by the dissemination of information and by co-operative effort, thereby helping forward to a proper conclusion those great problems and changes which are inevitable in this country.

THE PROPERTIES OF ELECTROLYTIC COPPER—MODULUS OF ELASTICITY.

By B. WELBOURN, Member.

(*Paper received 19 November, 1917.*)

In an Address to the Manchester Local Section,* the author referred to independent tests made in the National Physical Laboratory and by Mr. W. B. Woodhouse to determine the modulus of elasticity of solid hard-drawn copper conductors and suggested that an all-round value of 18,000,000 might be adopted in future. The interest aroused in this matter induced the author and his colleagues to undertake further investigation into the subject of the modulus which should be used for stranded conductors with Still's formula, and the results are given below. As showing the need for clearing up these points, it may be mentioned that other published values are as follows:—

	Solid Wires	Stranded Wires
Verband Deutscher Elektro-techniker	18,500,000	—
Kapper (German) †	19,000,000	11,400,000
Coombs (American) ‡ ..	16,000,000	12,000,000

In order to get actual values *under working conditions*, the tests were made on an experimental span of about 150 feet and special precautions were taken to prevent movement or bending of the terminal posts, which consisted of specially heavy tubular steel tramway poles set in concrete and well stayed.

It was thought desirable to test different sections of copper conductors to ascertain whether the modulus varied with different numbers of stranded wires. The sizes of conductors used were as follows:—

0·025 sq. in. = 7/0·068 in. bare hard-drawn copper strand.
0·05 ,, = 7/0·097 in. ,, ,,
0·10 ,, = 19/0·083 in. ,, ,,
0·25 ,, = 37/0·092 in. ,, ,,

These were standard E.S.C. strands taken from conductors made for overhead transmission lines and not specially manufactured. It is not thought that the results are in any way affected by the fact that the wires were drawn and stranded by one manufacturer.

Each test was made as follows:—

(1) The points of suspension of the experimental span were so arranged as to be level (a theodolite was used for levelling) and the supports quite rigid.

(2) The span length under test was pulled up to about 6 in. dip (i.e. just under half the breaking stress) and left for two hours to allow the strand to settle down.

(3) The strand was then let out to approximately 12 in. dip (i.e. about one-fifth of the breaking stress) and the dip d_1 at the centre of the span was measured.

(4) The span length was then loaded with an extra length of the same size of strand, this being bound to the first strand by means of a lapping of string, and the new dip d was measured. This was practically equivalent to loading the strand with its own weight of ice distributed evenly along its length.

(5) The measurements under (3) and (4) were made in still air and at the same temperature.

(6) On removing the extra length of strand under (4), the original strand returned to dip d_1 under (3), showing that the strand had not slipped at the terminations and that it had not been strained beyond the limit of proportionality.

(7) The weight of the binding string used under (4) was taken into account in working out the modulus.

From these results the modulus was calculated by the formula due to Professor Alfred Still, namely,

$$\frac{W_1}{d_1} - \frac{W}{d} = \frac{64(d_1^2 - d^2)MA}{3l^4},$$

where W_1 = weight per foot of unloaded strand (lb.).
W = ,, ,, loaded strand (lb.).
d_1 = dip in feet for W_1.
d = dip in feet for W.
M = modulus in lb. per sq. inch.
A = cross-section of strand in sq. inches.
l = length of span in feet.

The values obtained * were as follows:—

	0·025" (7/0·068")	0·05" (7/0·097")	0·10" (19/0·083")	0·25" (37/0·092")
A ..	0·025	0·05	0·10	0·25
W_1 ..	0·09967	0·2027	0·404	0·907
W ..	0·2035	0·4097	0·8124	1·937
d_1 ..	1·0	0·8333	1·00	0·666
d ..	1·526	1·3643	1·583	1·177
l ..	143·42	144·42	150·42	141·42
M (in millions)	20·11	19·84	17·36	15·46

It will be noticed that the modulus decreases as the number of wires in the strand increases, i.e. the modulus

* Repeat tests were made and the same results were obtained in every case.

* *Journal I.E.E.*, 1916, vol. 54, p. 54.
† "Overhead Transmission Lines and Distributing Circuits," by F. Kapper (translated by P. R. Friedlander).
‡ "Pole and Power Lines," by R. D. Coombs, p. 50.

of a strand apparently depends on the number of wires composing it.

From the above considerations the following may be taken as suitable working figures :—

7-strand cable	.. ..	20,000,000 lb. per sq. inch.
19-strand ,,	.. ..	17,500,000 ,,
37-strand ,,	.. ..	15,500,000 ,,

It would be interesting to have further experiments made with 7, 19, and 37-strand cables all built with the same size of wire, say, 0·092 in. ; it is hoped to carry out these experiments when industrial conditions become more normal after the war, and also to investigate the effect (if any) of different " lays " of strand.

The terminal posts are not stiff enough to permit of tests on 61- and 91-strand conductors, which are, however, seldom used except on short low-pressure lines with short spans and their modulus is not of much importance. A consideration of the above figures when plotted on a curve suggests, however, that the following values might be taken for them :—

61-strand	.. ..	14,000,000
91-strand	.. ..	12,500,000

As a result of this experimental work with long spans, the author wishes to modify his earlier recommendation of 18,000,000 for *solid* wire, which was chiefly based on the work at the National Physical Laboratory on quite short lengths of wire. The further work, now reported, confirms Mr. Woodhouse's result of 20,000,000 *for working conditions*, and this is the value which should be adopted when designing transmission lines.

The author wishes to thank Messrs. British Insulated and Helsby Cables, Ltd., for permission to publish the particulars of these tests.

PROCEEDINGS OF THE INSTITUTION.

600TH ORDINARY MEETING, 8 NOVEMBER, 1917.

(Held in the rooms of The Institution of Civil Engineers.)

Mr. C. P. SPARKS, Past-President, took the chair at 6 p.m.

The minutes of the Annual General Meeting held on the 17th May, 1917, were taken as read, and were confirmed and signed.

Mordey. Mr. W. M. MORDEY : It is a sad task I have to perform to-night. Four years ago we welcomed to the presidential chair William Duddell, who presided over us for two years with credit to himself and with advantage to the Institution. Four days ago he died. To-day, with other members of the Council, I have stood by his grave. We mourn the loss of a very brilliant man, whose death is a loss not only to the Institution but to electrical engineering and to science throughout the world. His work is known wherever electrical science is studied. He has died a young man as the result, we believe, of overwork. As a member of the Institution he had one distinction—shared now by our new President whom we greet to-night—he passed through the whole of our grades from studentship to President. Duddell had many great qualities as an engineer and as a scientist. He was a mathematician ; he was a physicist with a real physical insight ; he was a born experimentalist ; he was a ready speaker, a clear writer, and had great industry. Those who knew him were attracted by his personality and by his modesty. As a man he inspired a very great personal liking. It is not the time now to go into his work : that will be dealt with in our *Journal*. But I must recall his first appearance here, when, as a student, he read two very remarkable papers—papers which, if he had done nothing else, would have established his reputation as a great engineer. In 1899, with Professor Marchant, who was then also a student, he described to us his work on the oscillograph, and the next year he read that other very important and fruitful paper on the rapid pulsations in continuous-current arcs. The high character of that early work was maintained in all he did throughout his career. He received many honours here and abroad. He was a Fellow of the Royal Society and he received the Hughes Medal of that Society, a medal founded in memory of another Past-President, Professor Hughes, who in many ways as an experimentalist resembled William Duddell. The last, and in a way a pathetic, recognition of his work is this which I am allowed by his mother to show you—it is the insignia which reached her two days ago—he was himself too ill to receive the honour from the King. It was accompanied by this official memorandum : " Insignia of the Commander of the Order of the British Empire to be given to Mrs. Smithers, mother of William Duddell, who was made a Commander of the Order for his work as a member of the Board of Inventions and Research, Admiralty, and later as a member of the Munitions Invention Board. It was the strain of this work which no doubt led to his premature death." We may truly say, knowing what he did and how he worked, that he died in the defence of his country just as much as if he had fallen at the Front. Mr. Mordey

Mordey. I know that in your hearts you will honour the resolution it is now my sad duty to propose :—" The members of the Institution of Electrical Engineers have learned with profound regret of the death of Mr. William Duddell, C.B.E., F.R.S., Past-President of the Institution, and hereby desire to express their most sincere sympathy with his mother and sister in the great loss they have sustained through his death, and at the same time to record their deep appreciation of the invaluable services rendered by Mr. Duddell in the advancement of electric science and its applications."

The motion was carried in silence by the members standing.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : L. Birks, S. E. Britton, The Diesel Engine Users' Association, M. Farrer, F. W. Main, Dr. A. Russell, S. Sharp, S. Simpson, J. K. Stothert, " The 25 Club," H. W. Wilkinson, " Special War Donation " from " The 25 Club."

Library : W. R. Cooper, Captain R. Grierson, J. H. Johnson, Professor A. E. Kennelly, G. H Knibbs, Dr. H. W. Malcolm, W. Perren Maycock, J. W. Meares, The Board of Education, The American Association of Port Authorities, Messrs. Constable & Co., The Department of Scientific and Industrial Research, The Institute Elettrotecnica Radiotelegrafico, John Fritz Medal Board of Award, The J. B. Lippincott Company, The United States Department of Commerce, The United States Department of the Interior, Messrs. Whittaker & Co., and The Wireless Press, Ltd.

Museum : P. V. Luke, C.I.E.

The Premiums awarded during the last session * were then presented by the Chairman to such of the recipients as were present.

. Sparks. The CHAIRMAN : It is now my duty to induct the new President, Mr. Wordingham, into the chair.

Mr. SPARKS then left the Chair, which was taken by Mr. C. H. Wordingham amid applause.

. Sparks. Mr. C. P. SPARKS : Mr. Wordingham needs no introduction to the members of this Institution, for he has served a long apprenticeship as a member of Council and as vice-president. He has a very wide experience. In his early days he was associated with two of our best-known Past-Presidents, Dr. Hopkinson and Dr. Ferranti. He worked with the latter in connection with the Deptford scheme, and I had the pleasure of meeting him some 30 years ago and working with him in the early days of that pioneer high-tension transmission. Over 20 years ago Mr. Wordingham was chief engineer of the largest of our municipal electricity supply undertakings, namely that of the Manchester Corporation. His more recent activities have been as electrical adviser to the Admiralty. Mr. Wordingham has, as we all know, been an enthusiastic supporter of standardization, and I know of no one who has been a harder worker in the interests of the Institution. The painstaking work he has done on the many Committees of which he has been a member or chairman has been evident to all who have served on the Council for many years past. Then as to experience specially fitting him for the position of President, Mr. Wordingham some years ago was President of the Incorporated Municipal Electrical Association, and recently he has been appointed Chairman of the Electrical Research Committee which has been set up by the Government Department of Scientific and Industrial Research. A further honour has also been conferred upon him quite recently ; he has been made a vice-president of the British Electrical and Allied Manufacturers' Association. With such a record, I know of none more fitted to occupy the position of President of this Institution, and I have great pleasure in inducting Mr. Wordingham into the Chair. Mr. Sparks.

Sir JOHN SNELL : I had hoped it might have been someone's joyous duty during the retiring President's second year of office to congratulate him and ourselves upon the attainment of a victorious peace, but the mills of God are grinding more slowly than some of us had estimated and we are still in the throes of a world-wide war. Although we shall still have to continue the struggle for some time, we may, under Providence, trust that sooner or later we shall attain that victorious peace. To this effect there can be no question that Mr. Sparks's family is " doing its bit " : all his four sons and his distinguished brother, whom we are glad to find on the Council this session, Colonel Sparks, are helping to grind Prussian militarism exceedingly small. During the retiring President's two years of office he has had to navigate troubled waters. The removal from our lists of the enemy alien members and the introduction of a wider enfranchisement within the Institution are two of the measures which required very skilful navigation. Unfortunately for myself, during this period I have not been able to attend the meetings of the Institution as frequently as I should have liked, but I have kept sufficiently in touch with the work to know that the late President has busied himself in many schemes in the interests of the Institution, and amongst them I might mention the scheme for the instruction in electrical craftsmanship of disabled sailors and soldiers, which was so successful. Among others there is the selection of qualified persons from among our members for special posts either in the Navy or the Army or the Ministry of Munitions. All these matters have required constant thought on the part of the President, and upon him has devolved a very heavy responsibility. Without indulging in adulation or flattery, it is simply just that we should record our sincere appreciation of the energy which the retiring President has shown in the interests of the Institution, and to thank him for the tactful way in which he has conducted the business from the Chair. Having had some experience of it myself I sincerely congratulate my friend upon the admirable way in which he has upheld the dignity of the Institution and maintained the interests of it during two very critical years in our life. Therefore it is with a special pleasure that I move " That the thanks of the members of the Institution of Electrical Engineers be given to Mr, Sir John Snell.

* *Journal I.E.E.*, 1917, vol. 55, pp. 553, 668.

C. P. Sparks for the very able manner in which he has filled the office of President during the past two years."

Mr. R. T. SMITH: Sir John Snell has very properly eulogized some of our late President's very excellent qualities, but the one quality which has endeared him more than perhaps any other to those who have worked with him or under him has been his universal cheerfulness either in prosperity or adversity, especially in adversity. I hope that the cheery way in which he has conducted the most delicate questions and subjects, either in the chair or in the Council, may long remain a tradition for an example to future presidents. I have very great pleasure in seconding the resolution.

The resolution was carried with acclamation.

Mr. C. P. SPARKS: I thank members most heartily for the way in which they have passed this resolution, and I particularly wish to thank Sir John Snell and Mr. Roger Smith for the speeches they have made. If I have met with any measure of success during the past two years, it is primarily due to the very cordial way in which I have been supported by two different groups of members of Council and also by the local sections. I would emphasize the local sections, because I personally att ch an enormous importance not only to their present activities but also to their future work. One further factor is our Secretary. I feel that no President of this Institution could possibly fulfil his duties and the requirements at present placed upon him if it were not for the splendid way in which the Secretary prepares the work. I therefore wish especially to thank Mr Rowell for the very great assistance which I have received from him during the past two years.

The PRESIDENT then delivered his Inaugural Address (see page 1).

Mr. W. B. WOODHOUSE: I have very much pleasure in moving "That the best thanks of the Institution be accorded to Mr Wordingham for his interesting and instructive Presidential Address, and that, with his permission, the Address be printed in the *Journal* of the Institution." The electrical Press has from time to time suggested that some curious deadening influence falls on an electrical engineer when he joins the Council of the Institution. Young, active, zealous reformers pass through the door of the Council room and, as reformers, are heard of no more. Our President tells us that he has been a Member of Council for 14 years and one can only marvel at his fortitude, at his strength, and at his endurance that, after 14 years of this deadening influence, he should give us such an Address as we have listened to to-night. As members of the Institution, we have frequently had the pleasure of listening to Mr. Wordingham; he is never uninteresting; he is frequently provocative; and he is always fearless. I think the Address we have had to-night shows once more those very great virtues—that, whether the opinion be popular or unpopular, if he believes it he will express his views, and express them clearly and forcibly. The scope of the Address is so wide that it would be impossible at this hour to touch on any section. Its broad humanity and its shrewd comments on the problems with which the Institution will have to deal in the future will give food for thought to all the members for some time to come. The President has outlined what we individually, as electrical engineers, may do; he has outlined what the Institution as a body may do; and he has outlined them with great vision, and it rests with the members as a whole to give him the support that he so fully deserves.

Mr. S. EVERSHED: I do not know whether there happen to be any members of the Institution present who were not familiar with our President's high ideals and tremendous energy, but no one could be unaware of those two great qualities, after hearing his eloquent Address. Perhaps some members will be asking themselves: What is to be our future when we have a President with so high an ambition for the dignity of our Institution? If we want to know what a man is likely to do in the future, it is only necessary to look at what he has achieved in the past, and in seconding this resolution, I shall only speak of that part of Mr. Wordingham's professional life which was referred to by Mr. Sparks very briefly, namely, his career at the Admiralty as Superintending Electrical Engineer. Some 25 or 30 years ago, before Mr. Wordingham went to the Admiralty, electrical ideas and electrical discoveries began to disturb our Government departments and persistent persons insisted on introducing various electrical things into the Navy. The Board of Admiralty felt that they must dispose of these innovations in some convenient way, and looking round the various departments they selected the branch which deals with chain cables and anchors as being well fitted to look after electricity and electric cables. Electrical work continued to be superintended by that department until 1902, when Admiral Jackson's Committee was appointed to see whether something better could not be done. The Committee duly reported that electrical engineering should have a department to itself, and they nominated Mr. Wordingham to take charge of it. That was 15 years ago, and I remember the Navy under both regimes. I remember the days when electrical engineering in the Navy consisted substantially of a badly sparking dynamo placed in some odd corner, and supplying a number of 80-volt carbon lamps at a pressure of about 60 volts. Needless to say a complete revolution in electrical matters has been brought about under Mr. Wordingham's guidance. It is not all plain sailing for a civilian to step into a Government department, but what is the broad result of Mr. Wordingham's hard and sometimes perhaps disheartening work? The host of difficulties inherent in every application of electricity on board warships have been, one after another, attacked and surmounted, and to-day the electrical installation of a warship in the British Navy is a first-rate piece of electrical engineering of which Mr. Wordingham may well be proud.

The motion was carried with acclamation.

The PRESIDENT: I feel very keenly the kind remarks Mr. Woodhouse and Mr. Evershed have made, and I thank them very heartily indeed for their kind words; I also thank the members for the way in which they have received the resolution.

The meeting adjourned at 8.10 p.m.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 56. JANUARY, 1918. No. 270.

GAS FIRING BOILERS.

By T. M. Hunter, M.A., B.Sc.

(*Paper first received* 8 *June, and in final form* 2 *October*, 1917; *and read before* The Institution, 22 *November, before the* Manchester Local Section, 27 *November, before the* Birmingham Local Section, 5 *December, before the* Scottish Local Section, 11 *December, and before the* Dublin Local Section, 14 *December*, 1917.)

Synopsis.

Introduction—Calorific value of gas—Value of gas—Suitability of gas for boiler firing—Drying and cleaning gas—Heat transfer—Types of boilers—Boiler draught—Boiler settings: Air leakage; Radiation and conduction—Combustion: Theory; Practice—Gas measurement—Boiler control—Appendix.

Introduction.

In studying the subject of gas-firing boilers, the author has come across no books dealing with both the theoretical and the practical side of the question. This is all the more surprising, as gas-fired boilers have now been in use for a very great number of years. There are many excellent books on boiler-firing, but these do not generally touch the special problems which arise when seeking for the maximum efficiency and output of a gas-fired boiler. It is little wonder that engineers in charge of gas-fired boiler plants make so little progress in the direction of improving the results at their boilers. Most of them know that these results are wretched, and most of them have attempted, with little success in most cases, to make improvements.

The theory of the combustion of gas is simple; but to know what is the best combustion arrangement for any particular set of conditions, and, when this is fitted, to be able to run it so as to get the best results, are matters requiring much study and experience. Most engineers have not access to the formulæ and tables which would enable them easily to test the results they are getting at their gas-fired boilers, so the author has included in this paper a number of tables which he hopes may be of service.

The author does not claim originality for much of this paper. It is made up from information and experience gleaned here and there in years of study of the subject. If some of the matters seem very elementary, experts will forgive it for the sake of those not so well up in the subject.

Gas as a boiler fuel was first used in connection with blast furnaces somewhere about the middle of last century. Boiler-firing was the obvious use to which to put the gas recovered as a by-product in the manufacture of iron. Gaseous fuel is apparently the ideal fuel for boiler firing. It requires no stoking and no cleaning of fires. A whole battery of boilers can be attended to by one man, and a constant load is maintained independent of the efforts of manual labour. The main reason why blast-furnace gas has not been used with greater success is that it carries huge quantities of dust. This is deposited in the boiler flues, resulting in a constant decrease of the evaporation and requiring to be cleaned out every few weeks. Under these circumstances the possibilities of the fuel were not realized. About 25 years ago, gas-cleaning plants were introduced, which provided cleaned gas and did away with this disadvantage.

The introduction of regenerative coke-oven plants next provided quantities of gas, which was also used for boiler-firing. On account of the higher calorific value of coke-oven gas, very much smaller quantities had to be handled in order to obtain the same results from boilers. It was found that this gas could be brought into contact with the walls of boiler flues without being extinguished, and so brick-lined combustion chambers were not generally used for its combustion. It was, however, found that even with this richer gas the efficiency of gas-fired boilers was still very low.

The theory gained ground that gaseous fuel was unsuitable for boiler-firing, and that it was impossible with it to obtain anything like the efficiency or the evaporation obtainable in the same boiler by coal firing. This theory is still held by many engineers. It is the more surprising that this theory should have taken such a strong hold, as at the same time the most perfect combustion arrangements were invented for small quantities of gas. We generally connect these improvements with the name of Bunsen, and the Bunsen principle is at the back of most of the work that has been done on large volumes of gas, as well as on small volumes.

About 20 years ago the Mond by-product producer, followed by other producers, provided another source of gas in large quantities, and in some cases this gas was used for boiler-firing. The author thinks that in no case yet has gas-firing of boilers with by-product producer gas been made a commercial success, as it has been found that steam could be raised more cheaply from the coal direct, even after allowing for all the income from the sale of by-products. He does not wish to be misunderstood in saying this, as he firmly believes that there are modern producer and boiler plants even now on the market which can make the gasification and gas-firing proposition a commercial success under suitable conditions.

Many engineers came to the conclusion that they would have to give up boiler-firing with by-product producer gas as commercially impracticable, and they turned their eyes to gas engines to utilize the gas economically. Gas-cleaning plants had made the use of producer and blast-furnace gas possible in gas engines. It was soon seen that gas engines would produce 1 h.p. for at most 10,000 therms in the gas. This was at a time when it was assumed that some 20 lb. of steam per horse-power were required in a good steam engine. As this represented over 10,000 therms in the steam, and as this steam had to be generated in gas-fired boilers at not more than 50 to 60 per cent efficiency, the gas engine apparently was to be the engine of the future. Probably this would have been found true but for the adoption of steam turbines, which have reduced the steam per horse-power to about 10 lb. It was also found that the power per horse-power taken by gas engines increased rapidly as the load was reduced, whereas in turbines this was not the case. Turbines could be overloaded without danger, they could be made in units of very much larger size than the largest gas engines, and they were found, unlike gas engines, to be more economical in the larger sizes. In initial cost the turbine plant was cheaper, and in reliability and in cost of maintenance the gas engine was a very long way behind. It became evident that if gas-fired boilers could raise the steam at 75 per cent efficiency the results from a modern turbine set would be as good as those from a gas-engine set, while as regards reliability and the skilled attendance required, the steam turbine was unquestionably first.

There is no doubt that gas-fired boilers have now a greater future than ever. Probably the time is not so far distant when our present method of burning coal together with its valuable by-products will be considered obsolete, and possibly even illegal. It will then be replaced by some type of by-product producer or coal distillation plant yielding gas, and this gas will without doubt be largely used for boiler-firing purposes.

Calorific Value of Gas.

The calorific value of a gas is expressed as the number of therms contained in 1 cubic foot, or the number of calories contained in 1 cubic metre of the gas. It is the custom to quote the calorific value of a gas at normal temperature and pressure. In this country we quote the number of therms in 1 cubic foot at 60° F. and 30 in. mercury column. On the Continent, normal conditions are 0° C. and 760 mm. mercury.

The calorific value of a gas is found by burning the gas in a calorimeter and measuring directly the heat produced. This method reduces all the products of combustion to the temperature of the atmosphere, and thus condenses the water vapour arising from the combustion of hydrogen and hydrogen compounds. The value thus obtained is called the "gross calorific value" of the gas

In almost every case where gas is burned for practical purposes, the water vapour arising from the combustion escapes to the chimney as a vapour and is not condensed. It has therefore become the custom to treat the latent heat lost through the non-condensation of this water vapour, not as a charge against the boiler, but as a charge against the gas itself. The "net calorific value" of a gas—which is the value generally quoted—is the gross calorific value, less the latent heat of the water vapour of combustion.

If in any special case the products of combustion are cooled down so far that some of this water vapour does condense, a calorific value more nearly approaching the gross calorific value would have to be used, otherwise the results shown would be quite deceptive.

To calculate the calorific value from the analysis of a gas, we multiply the volume of each constituent by the calorific value of that constituent and add together the results. The following table shows the calorific values of the common constituents of gas; and an example is added to show the method of using the table. All the calorific values are taken at 0° C. and 760 mm.

	Gross Calorific Values		Net Calorific Values	
	Therms per cub. ft.	Calories per cub. metre	Therms per cub. ft.	Calories per cub. metre
Carbon monoxide, CO	344	3,062	344	3,062
Hydrogen, H_2	342	3,042	293·5	2,613
Methane, CH_4	1,063	9,460	960	8,598
Ethylene, C_2H_4 ..	1,724	15,300	1,027	14,480
Hydrogen sulphide, H_2S	659	5,860	619	5,513

Calorific Value of a Coke-oven Gas.

Analysis, per cent		Net Calorific Value		
H_2	49·1	0·491 ×	2,613	= 1,282
CH_4	32·6	0·326 ×	8,598	= 2,800
C_2H_4	3·1	0·031 ×	14,480	= 449
CO	8·1	0·081 ×	3,062	= 248
N_2	6·6			
O_2	0·5			4,779 calories per cub. metre
	100·0			= 537 therms per cub. ft.

The question of gross or net calorific value of the gas often leads to misunderstandings. It is evident that when gas is produced from coal in a coke oven or producer plant, the steam actually raised in boilers, per ton of coal put into the plant, is not affected whether we talk about the gas by its higher or lower calorific value. It is only when we investigate the efficiency of the

various parts of the plant that this question arises. The maker of the producer naturally wishes to use the higher calorific value of the gas so as to show a high producer efficiency, while the makers of the boiler and combustion arrangements wish to use the lower value because the difference between the two values is a loss which is not recoverable in the boiler. It is advisable in all contracts that it should be clearly specified which value of the gas is to be used, so as to avoid any possibility of friction.

Below are indicated the losses arising from the latent heat of this water vapour in the case of several typical gases, and suggestions are made as to the possibility of reducing these losses. In all the calculations given in this paper the net calorific value of the gas is the value used.

Value of Gas.

Among the by-products recovered from the distillation of coal, the manufacture of iron, the destructive distillation of coal and other processes, gas takes a very important place, and a much more important one than is generally realized by those who receive huge volumes of gas as a necessary and certainly welcome result of processes which primarily were not started for the purpose of manufacturing gas. It is common knowledge that in many modern manufacturing processes a very large proportion of the profits must of necessity be derived from by-products; it will therefore be worth while to consider more closely the value of gas when used under boilers.

Coke-oven gas.—Let us assume a coke-oven plant of 50 by-product ovens which deals on an average with 100,000 tons of coal per year and yields 6,000 cub. ft. of surplus gas of 450 therms per cub. ft. per ton of coal. Let us further assume that this gas is burned with the assistance of a suitable combustion arrangement, giving an efficiency of 80 per cent. It would then be possible to generate 220,000,000 lb. of steam from and at 212° F., which corresponds to 96,500 tons of steam per year.

If the value of a ton of steam to a colliery is taken at 1s. 3d., the value of the surplus gas will be just over £6,000, and each 1 per cent efficiency lost or gained will make a difference of £60. In other words, if the 100,000 tons of coal should produce 70,000 tons of coke, the total value of the gas will be nearly 1s. 9d. per ton of coke.

Blast-furnace gas.—The question of gas efficiency for the ironworks owner is a still more important one. It can be taken for granted that of the heat generated in a blast furnace 50 per cent is consumed by the process of making iron, and that the other 50 per cent is recovered in the blast-furnace gas.

If we assume one ton of coke to be used per ton of iron and the value of blast furnace coke to be 18s. per ton, 9s. per ton of iron is represented by the calorific value of the gas. Part of this gas must be used for heating the blast, but by far the greater part is available for the gas-fired boilers, gas engines, and the like.

If the stoves consume 30 per cent of the surplus gas, and if 10 per cent be allowed for losses through bell lowering, 60 per cent is available for boiler-firing, so that this portion of the gas with which we are chiefly concerned represents a value of nearly 5s. 6d. per ton of coke.

Let us assume that a ton of coke is equivalent to 27,800,000 therms; then 13,900,000 therms per ton of coke will be available in the gas, and if 60 per cent of that is surplus for boilers and gas engines, 8,340,000 therms can be burned under boilers.

If we again assume a boiler efficiency of 80 per cent, 8,340,000 therms would give 3·13 tons of steam from and at 100° C. per ton of coke. If the value of steam at ironworks is 2s. per ton, which corresponds to a coal price of 12s. and an evaporation of 6 lb. of steam per lb. of coal, we obtain 6s. 3d. worth of steam per ton of coke.

In order to realize the economical importance of the whole question, let us assume the case of an ironworks with four furnaces using on an average 3,000 tons of coke per week. The value of the coke for boiler-firing purposes is in their case £42,120 per year, and each 1 per cent difference in efficiency means a difference of no less than £421. It is hardly credible, yet true, that scarcely any ironworks obtains a boiler efficiency of more than 50 per cent, and that many get an efficiency much lower than this, so we see that small ironworks as described above are losing 30 per cent of £42,120, or £12,600 worth of steam a year, which could easily be recovered. The question of gas economy is thus seen to play a most important part in the financial prospects of ironworks.

Returning again to the case of the ironworks described above, the loss per ton of coke is at least 1s. 11d. when assuming an efficiency of 50 per cent. As efficiencies are frequently as low as 40 per cent the actual losses sustained are often over 2s. 7d. per ton of coke.

The manufacture of pig iron in Great Britain was some 10,000,000 tons a year before the war, so that if the average loss is only 2s. per ton, the formidable sum of £1,000,000 a year is sent up the stacks of the ironworks of Great Britain.

Producer gas.—Very few people at present use producer gas for boiler-firing. On the other hand, at many works there are considerable amounts of waste products, like belt pickings, coke breeze, shale, etc., which are very rich in combustible matters and yet unsuitable for boiler-firing purposes. Any proposition would be welcome which would render it possible to turn these waste products to profitable account without endangering the stability of the steam supply.

The fallacy of a producer gas proposal for boiler-firing without absolute security of the results obtained in the boilers is evident if the following figures are taken into consideration. A modern producer will yield nearly 75 per cent of the heat contained in the fuel as heat in the gas, and with the old combustion arrangements hitherto in vogue no higher efficiency than 50 per cent can be counted on, so that only 37½ per cent of the heat in the fuel appears as heat in the steam.

If we take a fuel containing 12,000 therms per lb., the total steam raised in a gas-fired boiler per lb. of fuel in the producer would not exceed 4½ lb. from and at 212° F. Then, again, 1½ lb. of this had to be returned to the producer in the blast, so that the net evaporation for outside purposes was only 3 lb. per lb. of fuel. Under ordinary circumstances the same fuels fired into boilers would have given 7 or 8 lb. of steam per lb. of fuel. With modern combustion arrangements an efficiency of 50 per

cent with producer gas can be raised to 75 per cent, so that fuel of 12,000 therms will give 7 lb. of steam per lb. of fuel; and as with the latest by-product recovery producers the steam necessary for producing by-products has been reduced to the amount necessary to drive the blowers, etc., the actual yield would be over 6½ lb. of steam per lb. of fuel. The result in steam for outside purposes is not materially worse than if the fuel had been burnt in the boilers, and the by-products are available to provide for depreciation, interest, and profit.

Suitability of Gas for Boiler Firing.

Coke-oven gas.—Coke-oven gas gives comparatively higher efficiencies than the two other kinds of gas in gas-fired boilers owing to the greater ease with which it can be burned. The nature of the gas, however, renders it difficult to make burners which will deal with large quantities of gas. The comparatively narrow flues of Lancashire boilers offer so much resistance to a speedy expansion of the burning gas that unless we use forced draught the evaporation from coke-oven gas in Lancashire boilers is confined to 5,000 to 6,000 lb. per hour. If, therefore, new boilers are contemplated it will always be advisable, provided that the quality of the water permits it, to choose water-tube boilers. Coke-oven gas is particularly suitable for firing water-tube boilers, and with suitable combustion arrangements evaporations of 5½ lb. per sq. ft. of heating surface can easily be obtained at the highest efficiency.

Blast furnace and producer gas.—Blast furnace and producer gas though of comparatively low calorific value, provided that they are clean and supplied under suitable pressure, will give good results, both in Lancashire boilers and in water-tube boilers. With Lancashire boilers evaporations of over 8,000 lb. per hour can be obtained, and with water-tube boilers 5 to 5½ lb. per sq. ft. of heating surface.

Blast-furnace gas we have to accept as it comes from the furnaces. It is so important that the iron made should be exactly what is required, that the kind of gas produced is never likely to be a matter of much concern to the blast-furnace manager. We must accept the fact that occasionally the gas is hardly combustible at all, and we must devise means to deal even with this condition.

The matter is different in dealing with producer gas. Gas is here a valuable product, though only the second product in point of value. The manager of the producer has it in his power to give us a gas which is much more or much less suitable for boiler-firing. We naturally wish the richest possible gas, as it is the easiest gas to burn. At one large Mond plant the gas was found to be just under 100 therms per cub. ft., while at many plants the gas is over 150 therms per cub. ft.

Apart from the question of calorific value, there is the question of the constituents of the gas. Two gases of similar calorific value can be shown which would give very different results on combustion. By-product producer gas, as is well known, is made by blowing steam and air blast into the producer fire, and the resulting gas contains hydrogen and CH_4. These gases, on burning, form respectively 1 and 2 cub. ft. of water vapour per cub. ft. of H_2 and CH_4, and the latent heat absorbed in forming this vapour, viz. 966 therms per lb. of vapour, is at present one of the inevitable losses in the use of the gas. The only way in which this heat could be recovered would be by cooling the chimney gases sufficiently to condense the water vapour, and this is impossible with our present economizers. To show the losses which are inevitable from this cause, the author gives the analyses of several gases, the net calorific value, and the number of therms lost by latent heat in the water vapour caused by combustion.

	Coke-oven Gas	Blast-furnace Coke Gas	Moore Producer Gas	Mond Producer Gas
	Per cent	Per cent	Per cent	Per cent
CO_2	—	12	12·7	16
CO	8·1	29	15·5	8
H_2	49·1	1·5	20·2	23·4
CH_4	32·6	0·7	2·2	3·2
C_2H_4	3·1	—	—	—
N_2	6·6	56·8	49·4	49·4
O_2	0·5	—	0·2	—
	Therms	Therms	Therms	Therms
Calorific value (cold gas)	540	112	132	130
Loss by latent heat in vapour of combustion	58½	1½	12½	17

These analyses of gases, as in the case of any other analyses given in the paper, must be taken only as examples. They are analyses of gases with which the author has actually had to do, but it is well known that even on the same plant analyses of gas vary greatly from time to time.

This table shows the great value of the losses from this cause. The author has purposely chosen two producer gases of similar calorific value, in order to bring out the point that a gas is more valuable for boiler firing (or for combustion in any way) which has a greater proportion of CO to H_2, other things being equal. Producer buyers should look carefully into this point when specifying new plant. A certain amount of steam must be blown into the producer in order to recover the ammonia, but at present far more is used than the amount necessary for this purpose in order to cool the fire. The author believes that some other method should be adopted for this cooling. The Moore producer, mentioned above, does part of this cooling by means of a water jacket. It has been suggested that much of this cooling could be done by some method such as by blowing in boiler flue gases carrying, say, 15 per cent of CO_2, and taking advantageof the absorption of heat which occurs when CO_2 is reduced to CO in the presence of heated carbon. This is known in America as the Eldred process. In this way the gas should be improved and much steam saved. The question, however, is still in the region of experiment.

Drying and Cleaning Gas.

It is very important that the gas should be dry when burned. At any temperature from 0° to 100° C. gas will take up a known amount of water as vapour and this amount can be found in an air-saturation table. If the gas has been cooled or washed in water, it is reasonable to assume that it is saturated with water to the amount corresponding to the lowest temperature to which the gas has been brought. As an example of the amount of water carried in this way, the author had recently to use, at 15° C. and 55° C. respectively, the two producer gases described in the above table. The former gas carried under 2 per cent by volume of water vapour, and the latter carried $15\frac{1}{2}$ per cent. This vapour must all be heated when the gas is burned, and it not only lowers the flame temperature, but also is responsible for carrying to the chimney a large quantity of sensible heat.

To show the actual loss from this cause, let us assume that we have cleaned blast-furnace gas from the same furnace, in one instance at atmospheric temperature with 12 to 15 grammes per cub. metre of water vapour, and in the other instance gas saturated at 70° C., carrying about 362 grammes per cub. metre. The analysis of the gas at 0° C. and atmospheric pressure is :—

	Per cent	Calorific Value
CO	29	965 calories per cub. metre 107 therms per cub. ft.
H_2	3	
CO_2	8	
N_2	60	

In both cases the gas is to be burnt under boilers with an excess of air of 25 per cent.

We have to ascertain, first of all, the air necessary for the combustion of this gas without excess of air, which is shown by the following table in cubic metres :—

	1 cub. m. of Gas	Oxygen needed	CO_2	H_2O	N_2
H_2	0·03	0·015	—	0·03	—
CO	0·029	0·145	0·29	—	—
CO_2	0·08	—	0·08	—	—
N_2	0·60	—	—	—	0·60
	1·00	0·160	0·37	0·03	0·60

Air required :

$0{\cdot}160 \times 4{\cdot}77 = 0{\cdot}762$ carrying N_2 .. 0·60

Total N_2 .. .. 1·20 cub. m.

25 per cent excess of air, $0{\cdot}762 \times 0{\cdot}25 = 0{\cdot}19$ cub. metre.

The combustion temperature of this gas when burnt with an excess of air of 25 per cent is 1,320° C., found thus, using the Le Chatelier formula * :—

Air and N_2	$1{\cdot}39 \times (0{\cdot}303\,t + 0{\cdot}000027\,t^2)$
H_2O ..	$0{\cdot}03 \times (0{\cdot}34\,t + 0{\cdot}00015\,t^2)$
CO_2 ..	$0{\cdot}37 \times (0{\cdot}37\,t + 0{\cdot}00022\,t^2)$
Total	$0{\cdot}568\,t + 0{\cdot}000124\,t^2 = 965$
	$t = 1{,}320°$ C.

* See Appendix.

Now take the gas at 70° C. Its temperature is about 55 degrees C. higher than atmospheric temperature, so that the additional sensible heat per cubic metre is 3 therms. This raises the calorific value of the gas to 110 therms. To this must be added the heat in the water vapour accompanying the gas, so that the calorific value of the gas plus the water vapour will be 113 therms or 998 calories. 1 cubic metre of aqueous vapour at 70° C. weighs 644 grammes (1 cub. metre of water vapour at 0° C. = 810 grammes : at 70° C. $\frac{810 \times 273}{273+70}$), so that 362 grammes of vapour carried by the gas will correspond to 0·562 cub. metre (0·445 cub. metre at 0° C.), and the combustion temperature is found thus :—

Air and N_2	$1{\cdot}391\,(0{\cdot}303\,t + 0{\cdot}000027\,t^2)$
H_2O ..	$0{\cdot}475\,(0{\cdot}34\,t + 0{\cdot}00015\,t^2)$
CO_2 ..	$0{\cdot}37\,(0{\cdot}37\,t + 0{\cdot}00022\,t^2)$
Total	$0{\cdot}72\,t + 0{\cdot}00019\,t^2 = 998$
	$t = 1{,}090°$ C.

This shows that there is a drop of 230° C. in the combustion temperature, which of course is a very serious matter. It is much more difficult to obtain complete combustion of this mixture of aqueous vapour and gas with an excess of air of 25 per cent than if gas alone is dealt with. It is also a well-known fact that the efficiency of a boiler depends in the first instance on the initial temperature of combustion, and if the latter is lower the efficiency of the boiler is certain to decrease. The first thing to be affected will be the evaporation per square foot of heating surface, which is certain to be considerably smaller if wet gas is used than with dry gas.

We have next to consider the effect of the water vapour on the efficiency of the boiler. From our former calculations the formula representing the loss is, in the case of the dry gas, $0{\cdot}568\,t + 0{\cdot}000124\,t^2$, and in the case of the wet gas $0{\cdot}72\,t + 0{\cdot}00019\,t^2$.

Let us assume that it would be possible to burn completely the dry and the wet gas with an excess of air of 25 per cent and to pass the waste gas to the stack in both instances at a temperature of 250° C. The losses through waste heat in the case of dry gas would be

$0{\cdot}568 \times (250-15) + 0{\cdot}000124 \times (250^2 - 15^2) = 142$ calories,

and in the case of the wet gas

$0{\cdot}72 \times (250-15) + 0{\cdot}00019 \times (250^2 - 15^2) = 180$ calories

per cub. metre of the gas burned. The loss through waste gas for dry gas would be 14·7 per cent of the total value of the gas, and for wet gas 18·7 per cent. Or, in other words, the presence of the water in the gas will cause an unavoidable and irredeemable loss of 4 per cent, in addition to the loss by the reduced flame temperature. Assuming in both cases 10 per cent loss through radiation and conduction, the actual efficiency for dry gas would be 75·3 per cent, and for the wet gas 71·3 per cent, which is equivalent to a drop in the output obtainable from the same quantity of gas amounting to 5·3 per cent.

So far as regards the efficiency, but it will also be

worth while to consider the evaporation obtainable in both cases. Let us assume that in both cases the boiler is working on its maximum load, that is to say that the boiler flues pass the maximum quantities of gas and air which the chimney draught can convey at the most favourable position of the damper. Let us assume that we are dealing with a 30 ft. × 8 ft. Lancashire boiler and that with a dry gas under the above described circumstances the highest possible evaporation was 6,000 lb. of water from and at 212° F. As the total efficiency of the boiler is 75·3 per cent, the total quantity of gas necessary in order to provide this evaporation contains 7,700,000 therms. At 107 therms per cub. ft., 72,000 cub. ft. of gas must be burnt per hour in order to obtain this evaporation. It was found above that for each cubic foot of gas 0·952 cub. ft. of air are necessary for complete combustion with an excess of air of 25 per cent. The air passed through the boiler will be 69,000 cub. ft. per hour. In order to facilitate our calculation let us assume that the weights of the gas and the air are the same. Then the total weight of 141,000 cub. ft. of air and gas will be 141,000 × 1·293 oz. = 11,400 lb., which represents the total weight of products of combustion that the boiler can possibly pass. Now at 70° C. each cubic foot of gas carries 0·0228 lb. of water, whilst the weight of the products of combustion from each cubic foot of dry gas will be 1·975 × 1·293 oz. = 0·158 lb. The weight of the products of combustion of wet gas is increased by 0·0228 lb. for each cubic foot of gas, giving a total weight of 0·1808 lb. for each cubic foot of dry gas plus water. The boiler is not capable of passing more than 11,400 lb. per hour, so that the maximum amount of gas to be dealt with would be 11,400 ÷ 0·1808 = 63,000 cub. ft. per hour. The total calorific value of the hot gas is 113 therms per cub. ft. The total heat admitted is 63,000 × 113, or 7,100,000 therms; the possible efficiency as above is 71·3 per cent; the heat in the steam is therefore 5,050,000 therms, which corresponds to 5 240 lb. from and at 212° F.

This somewhat lengthy calculation is useful as it shows that the simple presence of water in the gas can, under otherwise absolutely equal conditions, result in

(1) A drop of efficiency of 5·3 per cent,
(2) A drop in evaporation of 12·7 per cent,
(3) The loss due to lower flame temperature, which the author has not attempted to calculate.

From these calculations it is evident that an engineer who has to specify a producer plant, or a gas-cleaning plant, where washing of the gas is part of the process, should take care to specify the maximum amount of water vapour allowable in the gas supplied.

Contrary to a frequently expressed opinion the author does not believe that the dust in itself impairs seriously the heating value of blast-furnace gas; and the uncleaned gas has the advantage that it contains the sensible heat. The dust, however, may seriously affect the efficiency of the boiler. If two Lancashire boilers are run side by side, the one on cleaned and the other on uncleaned blast-furnace gas, it will be found that at first the results as regards both evaporation and efficiency are about the same. Soon dust will start to accumulate in the boiler flues, and as this dust is an insulating agent it will impair both the evaporation and the efficiency. After four or six weeks the dust accumulates in such large quantities that the evaporation falls and combustion may even take place partly in the stack instead of under the boiler. Where Lancashire boilers are to be fired, it will therefore generally pay to install a gas-cleaning plant, even at the expense of the sensible heat which is lost in the cleaning process.

Conditions are much more favourable with water-tube boilers, as with these it is often possible to clean the tubes without stopping the boiler. If liberal use is made of the steam lance, the proposition to put in a cleaning plant will certainly not be such a favourable one as in the case of Lancashire boilers.

It is not proposed here to enter into the advantages and disadvantages of the various systems of dry or wet cleaning. The ultimate choice in each case will depend on the first cost of plants and on the cost of attendance and maintenance. Heavy charges are involved for power consumption and for interest and depreciation on the capital outlay. But, whatever the cost should be, it must be borne in mind that the cheapest plant is not worth having unless it fulfils the following conditions :—

(1) The gas must be clean.
(2) It must be dry, and this is even more important than the cleanness.

In some cases where the gas can be cooled to a temperature of 80° C. without water injection, and where the ores contain only a small percentage of moisture, it is possible with a dry cleaning plant to obtain a dry, hot gas; whereas, where wet cleaning processes are used, or where water is injected for the purposes of cooling the gas, the gas is saturated and this water has to be eliminated.

So far as the author can discover, the cost of cleaning gas, inclusive of all charges, is about 2d. per 35,000 cub. ft., and is practically the same whether the wet or the dry process is used.

The sensible heat in blast-furnace gas per cubic foot is approximately as follows :—

Temperature of gas, C.	200°	250°	300°	350°	400°
Sensible heat, therms per cub. ft. . .	7	9	11	13	15

As cold blast-furnace gas varies from about 90 to 110 therms per cub. ft. this sensible heat is a large percentage of the total heat of the gas. Firing water-tube boilers with properly designed burners, and using the steam lance say twice a day to clean the tubes, the efficiency with uncleaned gas is certainly within 10 per cent of the efficiency with cleaned gas—probably within 6 per cent. On the other hand, with Lancashire boilers the average efficiency over 4 or 6 weeks with uncleaned gas is very considerably lower than with cleaned gas.

The decision as to whether it will pay to clean gas must therefore be made for each case separately, and depends on the peculiarities of the gas and of the dust, as well as on the kind of boilers used.

Heat Transfer.

Gaseous fuel as usually burned does not give the intense local heat and the heat-radiating surface of the coal fire. Rather the problem is that of a very hot gas which is cooled gradually as it travels through the boiler. It is like the problem of a coal-fired boiler with the fire-grate entirely outside.

The transfer of heat through a steel wall from hot gases to water consists of three parts—transfer of heat from gas to metal, transfer of heat through metal, transfer of heat from metal to water. The resistance to the transfer of heat in the second and third parts is exceedingly small when compared with the resistance to the transfer of heat from gases to metal. It is calculated for one case that the resistance to transfer of heat from gas to metal was 622 times the resistance to heat passing through the steel. This shows that the advantage to be gained by fitting, say, copper tubes instead of steel would be very small indeed. Again, the transfer from metal to water, if the metal has a clean surface, is also negligible compared with the gas-metal transfer. If, however, the metal carries scale on its surface the case is very different. Scale $\frac{1}{4}$ in. thick, assuming the scale to have the same conductivity as plaster of Paris, of which the specific resistance to the conduction of heat is 108 times that of iron, would add resistance to heat transfer equal to 18 per cent of the resistance of transfer from gases to steel.

The problem of finding the most satisfactory boiler for gas-firing is to be solved by the boiler which abstracts the heat most successfully from the hot gases passing. There are several lines along which improvements can be made.

The first is to increase the surface exposed to the hot gases. The greatest resistance to heat transfer is at the hot surface of the tube, and therefore this hot surface should be increased greatly without necessarily increasing the wet surface. This has been done in some boilers by fixing projecting pieces, or rings of angle iron inside the fire tubes, to increase the heated surface, and has resulted in a considerable improvement in heat transfer.

The second method depends on the fact that a square foot of heating surface at right angles to the gas flow is about 4 times more effective than a similar surface at 45°, and about 8 times more effective than a similar area parallel to the gas flow—at ordinary velocities of gas. Deflectors or retarders, of one kind or another, are put into the boiler so as to cause the gases after they have been fully burned to impinge on the tubes as directly as possible.

A third method, and probably the one most commonly used, is to put surfaces of brick or other refractory material in the boiler in such a way that the flames play upon them. These surfaces are raised to a high temperature and transfer the heat by radiation to the boiler tubes. Such surfaces, in order to give the greatest effect, must face the boiler tubes squarely, and must be as near as possible to these tubes. It is quite easy to heat surfaces at right angles to the line of gas flow, but usually very difficult to heat surfaces in the required position, as they generally have to be parallel to the gas flow.

The transfer of heat by radiation becomes much more rapid in proportion as the difference between the temperature of the two bodies concerned increases. From Stefan's law that the amount of energy radiated is proportional to the difference between the fourth powers of the absolute temperatures of the hot body and its surroundings, we can deduce the following table.

Difference between Hot Body and its Surroundings	Proportional Amount of Heat Radiated
100° C. to 0° C.	1
200° ,,	3·3
400° ,,	12
600° ,,	26
800° ,,	45
1,000° ,,	70

This table shows the necessity of raising our radiating surface to the highest possible temperature; and this again points to the use of the highest possible gas or air pressure in our burners in order to shorten the flame and make it more intense.

A fourth method depends on the theory that the difficulty of heat transfer from gas to metal is caused by a thin layer of cooled gas, which adheres to the surface of the metal and acts as a non-conductor. The stream of hot gases is made to scour very rapidly the surface of the tubes, and in this way the cooled gas is swept away and fresh hot gas is constantly applied. Very rapid heat transfer has been obtained by this means. In Nicholson's experiment a cylinder 10 ft. long was put into the flue of a Cornish boiler so as to leave a passage between cylinder and flue wall of only 1 in. all round. The gases were drawn through this passage at a velocity of 330 ft. per second by a high suction, probably 20 in. water-gauge. They were reduced in temperature from 1,260° C. to 425° C. in the passage, giving up sufficient heat to evaporate 36 lb. of water per sq. ft. of the tube per hour.

The author has had no experience with the Bonecourt boiler, but it is claimed by the makers that the heat is taken out of the gas by means of surface combustion on blocks of refractory material in the tubes, and that the heat is transferred by means of radiation from this material. Whether or not there is any surface combustion in the process as carried on in their latest boilers, the author thinks it likely that the high velocity of the gases through the tubes, in close contact with the walls and heating the refractory blocks, may be sufficient to account for the evaporation per square foot claimed. The suction required—16 in. water-gauge for the larger evaporations, equivalent to a velocity of about 250 ft. per second—would seem to bear this out. Unfortunately it is a costly matter to get these high suctions for the very

large volumes of hot gas with which we have to deal in boiler-firing.

It will be noticed that each of these methods involves either the use of power or the insertion of some obstruction in the boiler. There is no doubt that boiler users object to have any kind of brick erection inside a flue, as it may burn away and require renewal, and it must be removed to clean and inspect the flue. The author considers that for existing boilers the method of increasing the heating surface by the use of some kind of metal fitting in the flues is the one least open to objection. In regard to the use of power for forced draught or suction, it must always be remembered (although it is more usually forgotten) that such power is a charge against the boiler and that its cost must be deducted from the efficiency of the boiler before the net efficiency of the latter can be brought out. In some cases the power involved is quite small. To put the gas—or air—under 2 in. pressure, in the case of blast furnace or producer gas, requires power which would only reduce the boiler efficiency by $1\frac{1}{2}$ to 2 per cent, whereas the additional efficiency attained may be from 10 to 20 per cent.

Types of Boilers.

Lancashire boilers.—Boilers of this type are used very largely, and have to be utilized in the best way possible for gas-firing. It is a pity that 3-flue and 5-flue boilers are not more often used, as they not only give a larger heating surface, but also allow of smaller volumes of gas being burned in each flue. With smaller volumes of gas it is easier to burn the gas with a small excess of air. A disadvantage of the Lancashire boiler when gas-fired in any of the usual ways, is that the fall of temperature in the gases from one end of the flues to the other is not sufficient to set up good circulation of the water, as is done by the intense local heat of the fire when the boiler is hand-fired. In spite of all that is said against gas-fired Lancashire boilers, they will continue to be used and, in the author's opinion, successfully and economically used. As to the output to be got from these boilers, the author has experience of regular evaporations of over 9,000 lb. per hour from and at 212° F. from ordinary 30 ft. × 8 ft. boilers, both with producer gas and with blast-furnace gas. If we notice that the evaporation of 9,000 lb. per hour, i.e. nearly 10 lb. per sq. ft. of heating surface, corresponds very closely to the evaporation per square foot claimed for the Bonecourt boiler at the lower suctions, and that this evaporation is far higher than what we should expect from a water-tube boiler, we may develop a greater respect for the much maligned Lancashire boiler.

We have no other internally fired boiler in common use than the Lancashire boiler. Recognizing the advantage of boilers having flues when using feed water of doubtful quality, it is a matter for experiment to find the best pattern. The author's idea is to have a boiler with a considerable number of smaller tubes, forcing the gas to burn at the highest possible temperature in each; and to have no obstructions in the tubes and no mechanical suction. He believes that such a boiler, properly insulated, would give at least as good results as the best water-tube boiler. The points requiring elucidation are in regard to the proportion to be fixed between the length of boiler and the diameter of flue. These could be worked out at a comparatively small cost by experimenting on pipes of different diameter and length immersed in a water tank.

Water-tube boilers.—Wherever high-pressure boilers are to be installed, there is little doubt that water-tube boilers will be chosen if the available feed water is soft enough or can be suitably treated. It is important that sufficient combustion space should be provided for the huge volumes of gas to be burned, so that the gas may be fully burned before passing through the tubes. External combustion chambers should be avoided as causing unnecessary losses by radiation and conduction of heat, and because the highest temperature is not attained in the immediate vicinity of the tubes.

A good boiler should evaporate about 80 per cent of its load in the first bank of tubes, 15 per cent in the second, and 5 per cent in the third. The third bank is thus practically an economizer, and this accounts for the fact that the maximum evaporation of water-tube gas-fired boilers per square foot of heating surface is usually only $5\frac{1}{2}$ to 6 lb. per hour. In a large Stirling boiler fired with coke-oven gas and evaporating $5\frac{1}{2}$ lb. per square foot of heating surface, the temperature of the steam was 290° C., the temperature of the gases leaving the boiler was only 238° C., and the temperature of the feed water was 55° C.

When judging a boiler it will be safe to take the results obtained from coal-firing, as we can be certain that if the same boiler is fitted with good furnaces and arranged for gas-firing it will do somewhat better. In any case where gas-firing is concerned the choice of the right combustion arrangement is much more important than the choice of the best boiler. Up-to-date boilers do not differ in their results when coal-fired, and, when the same stokers are chosen, by more than 5 per cent at the outside; whereas, when it comes to gas-firing, one combustion arrangement can easily do 50 per cent better than another.

Another important question is the arrangement of superheaters in gas-fired boilers. When gas-fired boilers are arranged for hand-firing and gas-firing, the nozzles of the burners are apt to be too near the superheaters, so that in a good many cases the superheat imparted to the steam is more than is wanted. A superheat of about 85 degrees C. is the highest temperature which has been in common use in reciprocating engines and in the earlier turbines. To avoid raising the steam to a higher temperature than is required, it is advisable that the distance between the superheaters and the nozzles of the burners should be if possible more than 10 ft., so as to ensure that the superheater does not come into contact with the burning gas.

The ideal boiler for gas-firing has not yet been developed. There is no doubt that a water-tube boiler which is arranged so that the gas can be fully burned before passing through the tubes, and where the gas stream is kept at right angles to the line of the tubes by careful baffling, is the best boiler we have so far. To get higher outputs from such a boiler per square foot of heating surface is a matter calling for more rapid combustion of the gas, with more intense flame temperature, and this can easily be arranged where required.

The author has never come across a water-tube boiler

with small diameter tubes, such as, for example, the Yarrow boiler, gas fired. It seems probable from the theoretical point of view that the Yarrow boiler would give excellent results. As the tubes are only about 1 in. diameter, the proportion of heating surface touched by the gases, to the wetted surface of the tubes, is much larger than in the usual forms of water-tube boilers. As also the tubes are only about $\frac{1}{2}$ in. apart, the waste gases must pass between them at a high velocity. For these reasons the author would expect to get a high output and economical results with this type of boiler.

Boiler Draught.

The efficiency of a boiler depends for any given combustion arrangement on two factors—the gas pressure and the chimney draught. Gas pressure regulates the quantity of gas admitted to the boiler; the chimney draught regulates the air drawn in at the boiler front, and also the speed at which the products of combustion travel through the boiler. Given a gas which does not materially change in its composition, a boiler will always give uniform results provided that the gas pressure and the chimney draught are constant. If the products of combustion travel through the boiler at a certain constant speed the question of regulating the gas is a comparatively easy one; whereas if a boiler is joined to a stack, the question of draught is more difficult. The draught obtainable from a given stack varies with the temperature of the waste gas entering the stack and with the outside temperature of the atmosphere. For this reason the author would advocate where possible the adoption of automatic damper control, or of induced draught. With a constant draught and a constant gas pressure there should be no difficulty whatever in obtaining a constant maximum efficiency on a gas-fired boiler.

The theory is often propounded that the efficiency of a boiler increases with the velocity of the products of combustion, or, in other words, that if the products of combustion pass quickly over the heating surface of the boiler more heat is taken up from them than when they pass slowly. The author's experience leads him to the conclusion that this theory is incorrect. He has found that by increasing the velocity of the products of combustion he is in a position to increase the evaporation per square foot of heating surface, but the ratio between heat in steam and heat in gas, or in other words the efficiency, has decreased. He thinks the reason for this is clear. Increased velocity gives greater scouring action of the gases on the boiler tubes. Few boilers, however, are so designed that all the products of combustion are compelled to come into close contact with the tubes, and this defect is exaggerated if the gases are drawn along more quickly.

Boiler Settings.

The provision and upkeep of boiler settings sufficiently substantial to limit the conduction losses by insulating a boiler are equally necessary for coal and gas-fired boilers. The author proposes to go into the question rather fully from the gas-firing point of view, as it is a matter which has received far too little attention. It is preferable to have a poor boiler with a good setting than the best boiler with a bad setting.

The losses of efficiency by way of boiler settings are two-fold—the loss through infiltration of false air into the boiler through the brickwork, and the loss by radiation and conduction of heat from the boiler out through the brickwork. As regards the entry of false air, all this air must be heated to the exit temperature of the gases. The actual heat thus carried away to the chimney is not the whole of the loss, as there must also be taken into account the loss in temperature of the flue gases when mixed with the false air. This lowers the ratio of the temperature of the gases to the temperature of the boiler tubes, and therefore reduces the efficiency of the heat exchange. The loss by infiltration of false air is in many cases a loss of efficiency of 15 per cent or more. By looking up the tables given later, the actual loss for different proportions of air can be directly ascertained; but it should be remembered that as more false air is present, the exit temperature of the flue gases is usually higher and not lower, owing to the interference of this air with the heat exchange.

Air leakage.—The procedure in order to discover air leakages in boiler settings is very simple. If we assume a boiler using blast-furnace gas and find that when this gas is burnt with an excess of air of 25 per cent, 1·785 cub. ft. of dry waste gas contains 0·37 cub. ft. of CO_2, or that the CO_2 referred to the dry waste gas is 20·7 per cent; and if a sample of the waste gas taken at a distance of 15 ft. from the burner nozzles, or in the case of Lancashire boilers at the end of the first flue, yields this percentage of CO_2, the same proportion of CO_2 should prevail throughout the boiler, provided that there are no air leakages. Should there be a decrease in CO_2 it would prove the presence of air leakages, and by taking tests at varying distances from the burner nozzles, the places where air leakages occur can be exactly ascertained. As soon as these air leakages have been found they must be stopped. The first thing to be done in such a case would be to clean the outer side of the brickwork settings thoroughly, remove all loose mortar, and repoint the brickwork. This will, as a rule, greatly improve matters, but brickwork settings have generally a very large number of small crevices which are hardly visible to the eye. These crevices admit a great deal of false air, as the analysis of the waste gases shows. In order to close these it is necessary to cover the brickwork settings with several coats of thick tar, which should be renewed from time to time until the whole of the brickwork is covered with $\frac{1}{4}$ in. layer of tar. The tar will fill up all crevices and will provide nearly airtight boiler settings.

If one is set the task of getting the best out of a boiler which is known to have a very leaky setting, the procedure is as follows. Assuming the boiler to be provided with burners, and with sufficient gas or air pressure to force the gas and air through the burners, the damper is lowered until the flow of the products of combustion is checked, and the boiler is then run practically with no draught at all, or in a state of balanced draught. Of course this is liable to cause flames to come out at the air inlets round the burners, and care must be taken to keep sufficient draught to prevent this. The author knows of one case where this method was used on a water-tube boiler with a very leaky setting, and good results were got on the test which was carried out.

Radiation and conduction.—The losses through radiation and conduction of heat from a boiler are not sufficiently realized. When we consider that there are boilers which lose $1\frac{1}{2}$ per cent from these causes, and others which lose 15 per cent, it is evident that matters require attention. Owing to the difficulties of accurately measuring large volumes of gas in the state in which it is used for boiler firing, it is practically impossible to measure directly the radiation loss while gas firing a boiler. The usual practice is to test this loss when coal-firing the boiler, and to assume that the loss is the same while gas firing. The results of a large number of tests of well-protected boilers, which were published some time ago, showed that in no case was the radiation loss over $2\frac{1}{2}$ per cent.

One very common mistake, for which one has to pay very dearly, is to have boilers in the open air and not in a boiler house. As the radiation losses are dependent on the temperature inside the brickwork, the thickness of the brickwork, the temperature on the outside of the brick, and the wind velocity, it goes without saying that the radiation losses in the winter months with rain and high winds must be very much larger than in the case of summer heat. The radiation loss may be greatly reduced by building houses around boiler batteries. To reduce this loss to figures, a 30 ft. × 8 ft. Lancashire boiler working continuously on gas raises steam worth over £2,000 per annum at present. It is possible in almost every case to save 5 per cent in the radiation loss by putting a house round a boiler. £100 a year saved per boiler makes the cost of the house seem a foolish economy.

Another mistake which is very frequently made is parsimony when erecting the brickwork. The brickwork is often not thick enough. This is not a mistake confined to boilers, but occurs equally in gas producers and metallurgical furnaces. It is no economy to build light boiler settings, as the additional cost of heavier walls, etc., will very soon be repaid on the savings in radiation. For a Lancashire boiler in the open air, the radiation loss from the exposed front is about 1 per cent, showing a loss of £20 per annum, a sum which would pay many times for the cost of a suitable covering.

As a rule, modern water-tube boilers have suitably thick brickwork settings. In one installation of gas-fired Stirling boilers, and in a boiler house, the insulation is so good that in winter the boiler men asked for a stove in the boiler house on account of the cold.

Below are given the results of an actual test made by a boiler insurance company on a Lancashire boiler under its normal working conditions, and on the same boiler after the brickwork inside and out had been carefully pointed and the boiler front as well as the brickwork covered with a $2\frac{1}{2}$ in. coating of special insulating composition. Three runs were made under the old conditions and three under the new. The boiler was fired with coke.

These figures indicate the great value of the possible

	Tests before Insulation			Tests after Insulation		
Coke per sq. ft. of grate surface, in lb.	18·6	18·8	19·9	23·0	20·8	20·6
Ash in fuel, per cent	13·9	16·8	14·7	12·6	14·7	14·2
Waste gases at the damper—						
(*a*) Contents of CO_2, per cent	8·9	8·9	8·9	10·8	10·3	11·4
(*b*) Temperature	271° C.	282° C.	290° C.	310° C.	332° C.	329° C.
Steam per sq. ft. of heating surface per hour, in lb.	4·4	4·5	5·0	5·0	5·3	5·0
Temperature of feed water	15° C.	14° C.	15° C.	13° C.	13° C.	15° C.
Fuel, therms per lb.	11,400	10,800	11,000	8,700	10,400	10,200
Heat Balance Sheet.	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
Heat in steam	54·7	59·1	60·5	66·6	64·8	63·7
Loss—						
(*a*) In ashes	6·8	4·7	3·5	5·6	4·9	5·7
(*b*) In waste gases	18·5	20·1	18·8	21·0	20·8	18·8
(*c*) Radiation, conduction and unaccounted for	20·0	16·1	17·2	5·8	9·5	11·8

savings by making the insulation of the boiler as nearly airtight and heat-retaining as can be done. The saving in money value was somewhere about £130 per annum if the boiler was in continuous use.

In cases where it is not convenient or practicable to determine the losses of a boiler through radiation and conduction of heat by means of a careful test of the boiler with coal-firing, these losses may be roughly estimated at the following figures :—

	In Boiler House	In Open Air
Water-tube boiler	$1\frac{1}{2}$% to 3%	6% to 8%
Lancashire boiler	5%	10% to 12%

These figures can be used only for rough calculations, as to depend on them would in some cases lead to serious mistakes.

Combustion.

Theory.—Combustion is the name given to the chemical reaction between elements or compounds and oxygen which takes place at what is called the ignition temperature, a temperature varying for each element or compound. Before the reaction can take place, the fuel must have reached its ignition temperature, which is

usually attained by adding some external heat, for instance, burning wood, coal, or the like. The heat evolved by the reaction must be great enough to raise the temperature of the products of combustion to at least the ignition temperature. If the heat evolved is insufficient for this purpose then the reaction cannot continue by itself and will cease at once when no more outside heat is added.

Let us consider the combustion of hydrogen in pure oxygen. The equation for this reaction is : $2H+O=H_2O$, or in molecular weight $2+16=18$. The molecular heat of formation, taking water as uncondensed, is 58,000 calories ; in other words if 2 kg. of hydrogen are combined with 16 kg. of oxygen they form 18 kg. of water vapour and evolve a heat of 58,000 calories. These 58,000 calories must be sufficient to raise the temperature of 18 kg. of aqueous vapour above the ignition temperature of hydrogen, which is 600° C. As 18 kg. aqueous vapour correspond to 22·22 cubic metres, we can apply the Le Chatelier formula in the following manner :—

$$22{\cdot}22\times(0{\cdot}34\,t+0\ 00015\,t^2)=58{,}000,\quad\text{or}\quad t=3{,}191^\circ\text{ C.}$$

The heat evolved is therefore sufficient to raise the temperature of the products of combustion by 3,101° C., and as the ignition point is as low as 600° C. it is shown clearly that the reaction in this case continues once the ignition point is reached.

As an example of a case where the reaction cannot continue, owing to the fact that the heat evolved is not sufficient to heat the products of combustion up to ignition point, let us take the case of a gas containing 10 per cent of CO_2, 20 per cent of CO_2, 70 per cent of N_2. The calorific value of such a gas would be only 34 therms, or 306 calories. Let us assume that this gas is burnt in air with an excess of air of 50 per cent. This gas would theoretically require 20 per cent of air for combustion, and if 50 per cent excess of air is present, then each cubic metre of gas would give 1·31 cubic metres of products of combustion, of which 0·30 cubic metre is CO_2 and the balance oxygen and nitrogen. We apply the Le Chatelier formula as follows :—

$$(1{\cdot}01)\times(0{\cdot}303\,t+0{\cdot}000027\,t^2)$$
$$+(0{\cdot}30)\times(0\ 037\,t+0{\cdot}00022\,t^2)=306,\quad\text{or}\quad t=432^\circ,$$

or, in other words, the heat evolved is sufficient to increase the temperature of the products of combustion by 432 degrees C.

As the ignition temperature of carbon monoxide is over 600° C. it is evident that such a mixture could not burn unless sufficient heat were constantly admitted to keep the products of combustion at the ignition temperature.

In a boiler the flames play on the boiler flues which are cooled by the water, so that the heat evolved by the combustion of the gas must make up for the cooling effect of the boiler plates. It follows that while theoretically a gas containing, as only combustible, 20 per cent of CO, would be able to burn if not being cooled, in practice such a gas would be extinguished under a boiler.

For the scientific study of the combustion of gas we must first have the analysis of the gas to be used. From the analysis we can calculate the calorific value as shown above, the combustion temperature, and the analysis of the products of combustion.

If we wish to check the combustion by means of a pyrometer, it is of course first necessary to know at what temperature the best conditions for combustion are obtained in practice. In other words we must calculate the theoretical combustion temperature, and this varies for each change in the amount of excess air present. As regards the maximum excess of air allowable, it may be taken as a general rule that total combustion with an excess of air of 20 per cent is as favourable a result as should be expected.

A good combustion arrangement will give complete combustion with an excess of air of 10 per cent ; but with the usual industrial gases there are such large fluctuations in the compositon and calorific value that we do not usually dare to reduce the excess of air for continuous working under 20 per cent on account of the danger of having unburned gas in the waste gases.

Practice.—All this information is, however, of little use unless we have the power to remedy conditions. First of all it is essential that a proper combustion arrangement should be provided. Until this is done, little progress can be made. Good combustion can only be attained by providing an intimate mixture of air and gas. Complete combustion should take place very rapidly, at the highest possible temperature and with the smallest possible excess of air.

At different plants we find not only gases with different analyses, different temperatures, and different pressures, but the conditions also vary as to type of boiler, draught, and load. Each case has to be considered in all its details. It is not always safe to say that a certain combustion arrangement will suit because it is working successfully in another plant under somewhat similar conditions.

The original method of burning gas in boilers was simply to pass the gas into the flue from an opening near the door and to admit air by the door. The air and gas were left to mix as best they might. There are still far more boilers in this country fitted with this arrangement than with all other arrangements put together. The most usual improvement upon this method is the provision of combustion chambers in front of the boilers. Combustion chambers lose a serious amount of heat by radiation, and give the maximum temperature in the wrong place—outside the boiler instead of inside. Neither of these methods is of any use when the larger boiler outputs are required, as unburned gas appears in the waste gases as soon as the boiler load is forced. The usual efficiency of boilers fitted with these arrangements is about 55 per cent. Sometimes it is as high as 60 per cent, and often it is far below 50 per cent.

Combustion arrangements have to be designed to suit three different conditions of gas pressure :

(1) Steady pressure of 1 in. water gauge or more.
(2) Intermittent pressure, ranging constantly from 1 in. water gauge or more, to nil, with total stoppage of the gas flow and extinction of the flame.
(3) Very low gas pressure, or a pressure which may sometimes be high, but is low for considerable periods.

(1) For a steady gas pressure the Bunsen type of burner gives the best results. Such burners would have been generally adopted years ago but for the technical difficulties in designing them. It is easy to design the small Bunsen burner we use in the laboratory, but much more difficult to design burners for 80,000 or 120,000 cub. ft. of gas per hour.

A good burner of this type provides its own primary air which amounts to 60 per cent of the air necessary for combustion. The gas, acting as an injector, draws in this air and also mixes thoroughly the air and gas before ignition takes place. Whether or not the burner is doing its duty in this respect can be tested by taking a CO_2 reading of the gas-air mixture in the burner barrel. The secondary air, which is just as essential, is drawn in by the chimney draught, in conjunction with the injector action of the mixture emerging from the burner nozzle.

The maximum flame temperature should be found in the region of the boiler within a few feet of the burner, and there should be a minimum volume of flue gases carrying away heat to the chimney. The amount of gas to be burned in a boiler is only limited by the volume of gases with which the flues can deal under the conditions of gas pressure and chimney draught. Thus the boiler output is larger than it could possibly be with a bad combustion arrangement, in addition to the efficiency being improved.

(2) Intermittent gas pressure is found at most ironworks having no gas-cleaning plant. Each time a bell is lowered to admit the charge into a blast furnace, the gas pressure drops and usually the gas fails altogether. Ordinary Bunsen-type burners are useless under these conditions. They light back at the gas inlet inside the mixing tube, and each burner requires attention from the boilerman every time the pressure falls—say every 10 minutes—an impossible proposition. It is only very recently that this problem has been solved. Burners have been developed which draw in and mix primary air with the gas in a similar manner to the Bunsen burner. These burners work on the injector principle. Their mixing tubes are made conical, expanding in cross-section from the gas inlet to the burner nozzle. This form offers practically no frictional resistance to the flow of the mixture of gas and air. It is well known that a flame travels through a mixture of air and gas at a certain definite speed for a known mixture. The burners are so proportioned that the speed of the mixture of air and gas at the burner nozzle is greater than the speed of the explosive reaction of the flame, and therefore, when the gas pressure is present, the gas burns at the end of the burner. When the gas pressure falls the gas burns at that point where the speed of the gas-air mixture corresponds to the speed of the flame. When gas fails, the flame is extinguished and a small coal fire is kept in the boiler to ignite the gas when it returns. As soon as gas pressure returns, the velocity of the gas-air mixture forces the flame out of the mixing tube and combustion continues at the burner nozzle as before.

It is found that this burner automatically adjusts, over considerable variations of gas pressure, the weight of primary air drawn in to the weight of gas passing, on account of the absence of friction in the mixing tube. At one English ironworks, on a Lancashire boiler working at a gas pressure of about 1 in. water gauge, it is found that the temperature of the waste gases is 315° C., while the temperature in neighbouring boilers fitted with the old combustion arrangement is from 700° C. to 900° C., with combustion still taking place at the dampers.

(3) To deal with gas at a very low gas pressure, and to get a good mixture of gas and air, is impossible without mechanical assistance. No burner will mix them properly. A Bunsen-type burner would light back at once at such low gas pressures. The problem can be solved in two ways: (*a*) Air and gas can be drawn in by means of a fan, mixed completely in the fan, and the mixture supplied to the boiler by a simple pipe; or (*b*) power to work a Bunsen-type burner can be got by raising either the gas or the air to a sufficient pressure. The method of complete mixing is being tried in America, but the author has so far no figures for it. He has no doubt that it can be done successfully, but it is evident that it has certain risks.

If the pressure of either gas or air is raised to 2 in. or more, the conditions are then similar to those in (1) where a steady gas pressure exists. The mixing in the burner is done either by the gas or by the primary air entering under pressure; and the secondary air is drawn in at the burner nozzle as usual. To raise the gas pressure, a fan is inserted in a by-pass on the gas main, and three valves are provided to cut off the fan on each side and to close the gas main when the by-pass is open. The fan to raise the air pressure has only to deal with 60 per cent of the air required, but an air main is required connected to each burner. Although both these methods are costly, the results, both as to additional boiler load and as to improved efficiency, are so satisfactory as to pay many times over for the outlay.

When a short, intense flame is required, we must use either air or gas under considerable pressure. This method is well known in the case of gas furnaces for reheating and melting. From 1½ to 2 lb. per sq. in. pressure on the air supply is the most suitable pressure, though excellent results are got with 12 in. (water gauge) pressure. The whole of the air needed for combustion is supplied by the mixing arrangement, no secondary air being used. The author believes that by this method, which puts the boiler under pressure, and by simply drawing off the products of combustion by the chimney draught, we should make a considerable advance in the direction of larger boiler outputs combined with high efficiency.

On the point as to the necessity for intimately mixing air and gas before combustion starts, it has been found in America by a series of experiments on water-tube boilers that a smaller combustion space is needed in proportion as the air and gas are more intimately mixed in the burners.

Preheated air and hot gas are of great advantage for boiler firing. Air preheated to 190° C. was used at one plant, with producer gas of 150 therms per cub. ft. The sensible heat of the air added 5 per cent to the calorific value of the gas, and thus raised the flame tem-

perature. It depends upon where the heat is got, whether it really adds anything to the total efficiency. There is one arrangement in which air is preheated by coming through the centre of the flue of a Lancashire boiler in an iron pipe from the back of the boiler. The air is supplied very hot, but the heat is got by taking from the products of combustion heat which should have gone into the steam. In another arrangement, gas is supplied through a pipe which passes into the boiler flue and bends back again, so that this bend is actually in the flame. The gas is heated very considerably, but again at the expense of the temperature of the products of combustion. These arrangements probably do account for some small gain in efficiency over the old methods of gas-firing; but if the air or gas is heated by waste gas, say in an economizer or in passages outside the walls of the boiler, the heat then supplied is all clear gain.

There are certain cases in which a good combustion arrangement seems to fail. The peculiarities of a boiler may baffle all attempts at improvement. These are the cases which require hours of study and the use of every means which experience suggests. The solution is often found in bad design of flues, or in the defective condition of internal flue walls or baffles, and sometimes in a peculiarity of gas conditions—the conditions being different from those existing when the combustion arrangement was designed.

Gas Measurement.

If the evaporation of a boiler is known, the only other thing required is to know the quantity of gas consumed. Here a serious difficulty arises. Wherever a large quantity of gas is concerned, gas measurements are difficult, and where the gas is of high and varying temperatures and carries a large quantity of dust, they are next to impossible. Where smaller quantities of gas are concerned, as for instance in the case of coke-oven plants, a meter of the rotary type may be installed to obtain a constant record of the distribution of the gas over the whole plant. In the case of producer gas and blast-furnace gas, where often millions of cubic feet of gas per hour have to be measured, a meter of the rotary type is out of the question, owing to the cost and to difficulties arising from the tar and dust in the gases. In that case velocity measurements, with the assistance of the Pitot tube or throttling disc, or anemometer, can be taken. Velocity readings taken thus cannot be trusted to give absolute readings, but they are very effective in giving readings which are relatively correct from day to day. To obtain the actual values there is no other way but to resort to theoretical calculation and to draw up a balance sheet for the carbon. By the use of a gasometer, of course, really reliable gas measurements can be made, but in most cases a gasometer is not available.

Certain points require to be watched when using gas meters unless the gas is quite free from dust and tar. A meter of the rotary type should be calibrated by means of a gasometer, both before and after use, with the actual gas it is measuring. If this is not done, large errors may arise. In one case lately during a 4-days' test, the tar in the by-product producer gas partly choked up the holes in the guide plate of the rotary meter and the readings were useless, getting gradually higher as the velocity of the gas increased, until the plate became altogether choked. With Pitot tube meters, the Pitot tube must be kept clean, and should be examined and blown out at short intervals. Meters working by the difference of pressure on the two sides of a throttling disc in the gas main are, the author thinks, less apt to deceive than Pitot tube meters, because they are not so liable to be affected by eddies in the gas flow. Velocity readings should never be used unless the pipe in which they are taken is straight for about 10 diameters' length on each side of the point of reading.

The author has used both Pitot tube and throttling disc gas meters at several different plants, and on the whole has had reason to be satisfied with the readings they gave of relative volumes. He does not know of any English make of meter working on these conditions. Before the war he did his best to get one of the large English makers to manufacture these meters, and gave him all information, even offering to lend him a meter which he had found to be of the best German make, but without success. If a meter of this type is to be bought, care should be taken to see that the readings of the float are transmitted directly, without any levers or magnification, to the chart. The difference of pressure which is being measured is so small that one cannot afford to allow the possibility of any such errors in the instrument.

Boiler Control.

We have got to accept the fact that the human element in almost every case is an important factor in boiler control. Of course an arrangement can be provided whereby the air supplied to a boiler is controlled completely by the quantity of gas passing, and where the chimney draught is kept constant, either by induced draught or by damper control. Still we recognize that the cost and the added complication of such arrangements are such that few managers will install them, even though perfect combustion conditions would always prevail.

There are three methods by which we can test what results are being got by a boiler, namely, (1) by measuring the gas supplied and the water evaporated, (2) by analysing and taking the temperature of the waste gases, as described above, and (3) by taking the combustion temperature. All these methods are good. The chemical method is slower and more laborious than the pyrometer method, but it is cheaper and gives much more information.

For testing the combustion temperature a pyrometer junction is inserted in each boiler flue within a short distance of the nozzle of the burner. All these junctions can be wired to one dial, with switches to connect each junction in turn to the dial. Such an arrangement is especially desirable if the engineer in charge has no time to be constantly at the boiler plant. He can have the dial in his office and can at any moment read the temperature in front of each burner nozzle, and give

instructions to the boilerman to attend to such burners as are not working satisfactorily.

A CO_2 recorder on the boiler flue is an excellent check on the results. It will be realized, however, that very deceptive deductions may be made from the readings of this instrument. Although the CO_2 reading is good, there may be unburned CO present, causing serious losses. If an instrument were fitted to record CO_2 and CO simultaneously, it would be the ideal arrangement for the chemical control of gas-fired boilers, and the author sees no reason why such an instrument should not be made and sold at a reasonable price.

It is wonderful to see how an untrained man who has long experience of gas-firing and is interested in his work can set his boiler to get very nearly as good results as would be got by chemical control. Unfortunately we more often have to do with the boilerman who thinks that gas burns itself, and who cares nothing about the colour of the flame. It is only fair to say that hardly any works give their men any inducement to economical firing, either by bonus payments or even by providing the men with any kind of apparatus to assist them. There is no doubt that a gas-pressure gauge should be fitted, if not at each boiler, at least at every range, and that it should be in a place easily seen by the boilerman. In addition to this, a differential draught gauge should be fitted to each boiler, showing the difference in draught between the front and back of the boiler, and a plain mark should be made on the dial at the reading which the boilerman is to maintain by means of his dampers. With these gauges it is an easy matter to instruct a boilerman how to control his burners without trusting alone to the appearance of the flame, even under varying conditions of gas pressure and chimney draught. On large boilers working at steady gas pressure it pays well to install automatic damper control to maintain a uniform chimney draught.

Water meters are a necessity for careful boiler control. In some Continental works a separate meter is fixed to each boiler, but at least one meter to every range of boilers is necessary. Gas meters should also be installed.

In all large works a man should be appointed to take general charge of the steam output. He need have no great chemical or engineering training, as his business is simply to run his boilers at their maximum efficiency, and all engineering matters would be reserved for the engineer or manager. A suitable man can be got for £4 a week in ordinary times, but of course he would require a little training from a chemist or engineer before he fully understood his duties. The author has trained one such man and found that he picked up the requirements very quickly and carried out his duties most successfully. At a works raising 100,000 lb. of steam per hour the value of the steam is about £40,000 per annum. If the man in charge of the boilers, by his effective control, improves the efficiency by only 5 per cent, the £2,000 saved will pay his salary many times over. In addition, there is the advantage that the maximum possible supply of steam will always be secured. Even with the best combustion arrangements, the result of intelligent control will be a saving of at least 5 per cent as compared with the results to be attained with the same installation run simply by boilermen, so that there is no possible excuse for a company that neglects to appoint such a man. In large American works the steam engineer is a recognized necessity, and he is a highly paid official.

The apparatus for boiler control will cost a considerable amount, and it must not be overlooked that the best outfit of recording instruments is useless unless a constant and intelligent use of them is absolutely enforced. All the temperatures, pressures, volumes, and analyses taken, should be entered up in a special book. At least once a week a balance sheet should be drawn up, showing the allocation of the gas to each part of the work and the results obtained therefrom. This should be submitted to the manager weekly, with the necessary explanation in case any result falls short of the required efficiency. If, in addition to this, the boilermen and the man in charge of the boiler plant are given a premium for maintaining good results, boiler control will soon develop into a fine art, and prove an important source of revenue.

APPENDIX.

The Le Chatelier formulæ for the specific heat of gases at any temperature, have been used throughout the paper.

Formerly the specific heats at high temperatures were unknown. The results attained by assuming that specific heats were constant at all temperatures, e.g. in the calculation of flame temperatures, were known to differ by hundreds and in some cases by thousands of degrees from the temperatures as actually measured. Mallard and Le Chatelier determined the increase of specific heat with rise of temperature. By doing this they have removed this great discrepancy between theory and practice.

The actual specific heat of 1 cubic metre at temperature $t°$ C. is given by Le Chatelier as follows :—

for N_2, O_2, H_2, CO $= 0{\cdot}303 + 0{\cdot}000054\ t$,
for $CO_2 = 0{\cdot}37 + 0{\cdot}00044\ t$,
for vapour $H_2O = 0{\cdot}34 + 0{\cdot}00030\ t$.

The mean specific heat between 0° and $t°$ is the specific heat at 0°, plus half the increase, e.g. for $CO_2 = 0{\cdot}37 + 0{\cdot}00022\ t$.

The quantity of heat needed to raise 1 cubic metre, measured under standard conditions from $t_1°$ to $t_2°$ is, in calories,

for N_2, O_2, H_2, CO $= 0{\cdot}303\ (t_1 - t) + 0{\cdot}000027\ (t_1^2 - t^2)$,
for $CO_2 = 0{\cdot}37\ (t_1 - t) + 0{\cdot}00022\ (t_1^2 - t^2)$,
for $H_2O = 0{\cdot}34\ (t_1 - t) + 0{\cdot}00015\ (t_1^2 - t^2)$.

To use these formulæ we must first calculate from the analysis of the gas being burned what is the composition of the products of combustion. The theoretical

composition is found as follows (the O_2 and air theoretically required are also shown) :—

Product of Combustion	Proportions of Constituents of Gas—by Volume
CO_2 from	$CO+CH_4+2C_2H_4$
H_2O ,,	$H_2O+H_2+2CH_4+2C_2H_4+H_2S$
SO_2 ,,	H_2S
O_2 ,,	$\frac{1}{2}CO+\frac{1}{2}H_2+2CH_4+3C_2H_4+3\cdot2H_2S-O_2$
N_2 ,,	$N_2+3\cdot771\times O_2$
Air ,,	$4\cdot771\times O_2$

An example of the use of this is given in Table 2.

When the composition of the waste gases is known, the loss by sensible heat in the waste gases at any temperature, and with any excess of air, is calculated as follows.

Let us take the coke-oven gas given in Table 1 and calculate the loss if it were burned with only the theoretical quantity of air, and if the waste gases passed away at 200 degrees C. above atmospheric temperature. The waste gases from 1 cubic metre of live gas are

$CO_2=0\cdot469$, $H_2O=1\cdot205$, air and $N=3\cdot976$ (see Table 2).

For CO_2
$=0\cdot469\ (0\cdot37\times200+0\cdot00022\times200^2)\ =\ 38\cdot8$
for H_2O
$=1\cdot205\ (0\cdot34\times200+0\cdot00015\times200^2)\ =\ 89\cdot2$
for air and N_2
$=3\cdot976\ (0\cdot303\times200+0\cdot000027\times200^2)=244\cdot5$

Total . . . . . 372·5 calories.

The calorific value of the gas was 4,779 calories per cubic metre (Table 1), so that the loss by sensible heat is $372\cdot5/4,779=7\cdot7$ per cent (as shown in Table 4).

The combustion temperature t of the gas is calculated thus.

For the above coke-oven gas burned with 17 per cent excess air, Table 3 shows the composition of the products of combustion to be

$CO_2=0\cdot469$, $H_2O=1\cdot205$, air and $N_2=4\cdot751$.

The equation giving the temperature is

for CO_2 $0\cdot469\ (0\cdot37\,t+0\cdot00022\,t^2)$
for H_2O $-1\cdot205\ (0\cdot34\,t+0\cdot00015\,t^2)$
for air and N_2 $+4\cdot751\ (0\cdot303\,t+0\cdot000027\,t^2)$
$=4,779$ (the calorific value in calories).

Whence we find that $t=1,750°$ C.

Recently calculated combustion temperatures for samples of blast-furnace coke gas and Mond producer gas were 1,350° C. and 1,470 C. respectively, using 25 per cent excess of air.

We require also to be able to calculate the losses by latent heat and by unburned gas in the waste gases.

To find the latent heat in the waste gases from the above coke-oven gas: Table 1 shows that 1 cub. ft. of gas produces 1·205 cub. ft. of water vapour when burned. Reduce this to pounds of water by multiplying by 0·05022, and we have

$1\cdot205\times0\cdot05022\times966=58\cdot5$ therms

as the required latent heat in the waste gases formed by the combustion of 1 cub. ft. of this gas.

To calculate the loss due to unburned gas present in the waste gases: suppose the test showed CO = 1 per cent for the above coke-oven gas, with $CO_2=8$ per cent; then 1 per cent of 5·22 (the dry volume of the waste gas, Table 3) gives 0·0522 cub. ft. of CO unburned per cub. ft. of live gas. The loss is thus $0\cdot0522\times344=18$ therms per cub. ft. of live gas. As the gas was 537 therms per cub. ft., this is a loss of 3·3 per cent.

A reading of 1 per cent CO in the waste gas from the blast-furnace coke gas used in Table 5, with 13 per cent of CO_2 would by a similar calculation give a loss of $0\cdot02977\times344=10\cdot4$ therms (Table 7) = 8 per cent.

The loss corresponding to 1 per cent of CO in the waste gas is larger or smaller according to the volume of the waste gases of which it is a proportion. This volume we can find from the readings of CO_2 and CO by looking up the tables.

The following tables must be adapted, by the calculations given, should the gas to which they are to be applied differ from the gases for which they are calculated. It will, however, be found that they apply, as they stand, to quite a considerable range of small variations in composition.

The author wishes to acknowledge his debt to Richards' "Metallurgical Calculations" for the great help it has been to him in this work.

TABLE 1.—COKE-OVEN GAS.

Composition Per cent		Net Calorific Value of the Gas	
H_2 49·1	H_2	0·491 × 2,613 =	1,282
CH_4 32·6	CH_4	0·326 × 8,598 =	2,800
C_2H_4 3·1	C_2H_4	0·031 × 14,480 =	449
CO 8·1	CO	0·081 × 3,062 =	248
O_2 0·5			
N_2 6·6			4,779 calories per cub. metre = 537 therms per cub. ft.
100·0			

TABLE 2.—COKE-OVEN GAS.

	1 cub. ft. of Gas	Oxygen Required	Products of Combustion CO_2	H_2O	N_2
N_2	0·066	—	—	—	0·066
H_2	0·491	0·245	—	0·491	—
CH_4	0·326	0·652	0·326	0·652	—
C_2H_4	0·031	0·093	0·062	0·062	—
CO	0·081	0·041	0·081	—	—
O_2	0·005	—0·005	—	—	—
	1·000	1·036	0·469	1·205	0·066

Air required :
$1\cdot036\times4\cdot77=4\cdot94$ cub. ft. carrying N_2 3·91

Total N_2 . . . . 3·976 cub. ft.

Composition of Waste Gas Dry	Wet	Theoretical CO_2 Dry	Wet
CO_2 0·469	0·469	10·8 %	8·32 %
H_2O —	1·205		
N_2 3·976	3·976		
4·445	5·650 cub. ft. per cub. ft. of live gas.		

TABLE 3.—COKE-OVEN GAS.

Composition of Waste Gas, from 1 cub. ft. of Gas, at Varying Percentages of CO_2.

Per cent CO_2 on Dry Waste Gas	CO_2	H_2O	Air and N_2	Total Dry Waste Gas	Total Wet Waste Gas	Excess of Air	Excess of Air, per cent
10·8	0·469	1·205	3·976	4·475	5·650	Nil	Nil
10	,,	,,	4·221	4·69	5·895	0·316	6½
9	,,	,,	4·751	5·22	6·425	0·846	17
8	,,	,,	5·401	5·87	7·075	1·496	30
7	,,	,,	6·231	6·70	7·905	2·236	45
6	,,	,,	7·351	7·82	9·025	3·446	70
5	,,	,,	8·931	9·40	10·605	5·025	100

TABLE 4.—COKE-OVEN GAS.

Losses through Sensible Heat in Waste Gases at Varying CO_2 for Various Rises of Temperature.

Per cent CO_2 on Dry Waste Gas	200° C.	250° C.	300° C.	350° C.	400° C.	Flame Temperature
	Loss %	Loss %	Loss %	Loss %	Loss %	C.
10·8	7·7	9·8	11·9	14	16·2	1,900
10	8·1	10·2	12·4	14·7	16·9	1,835
9	8·8	11·1	13·5	15·9	18·3	1,750
8	9·6	12·2	14·7	17·4	20·0	1,660
7	10·7	13·5	16·3	19·3	22·2	1,520
6	12·2	15·3	18·5	21·8	25·2	1,375
5	14·2	17·9	21·6	25·4	29·3	1,210

TABLE 5.—BLAST-FURNACE COKE GAS.

Composition Per cent		Calorific Value	
CO	29	CO	0·29 × 3,062 = 888
CO_2	12	CH_4	0·007 × 8,598 = 60
CH_4	0·7	H_2	0·015 × 2,613 = 39
H_2	1·5		
N_2	56·8		987 calories per cub. metre = 112 therms per cub. ft.
	100·0		

TABLE 6.—BLAST-FURNACE COKE GAS.

	1 cub. ft. of Gas	Oxygen Required	Products of Combustion CO_2	H_2O	N
CO ..	0·29	0·145	0·29	—	—
CO_2 ..	0·12	—	0·12	—	—
CH_4 ..	0·007	0·014	0·007	0·014	—
H_2 ..	0·015	0·007	—	0·015	—
N_2 ...	0·568	—	—	—	0·568
	1·000	0·166	0·417	0·029	0·568

Air required: 0·166 × 4·77 = 0·79 cub. ft., carrying N_2 0·624

1·192

Composition of Waste Gas Dry	Wet	Theoretical CO_2 Dry	Wet
CO_2 0·417	0·417	25·9 %	25·4 %
H_2O —	0·029		
N 1·192	1·192		
1·609	1·638		

Moisture in this case will only affect second decimal in loss per cent, and can therefore be neglected.

TABLE 7.—BLAST-FURNACE COKE GAS.

Composition of Waste Gas from 1 cub. ft. of Gas at Varying CO_2.

Per cent CO_2	CO_2	Air and N	Total Volume	Excess of Air	Excess of Air, per cent
25·9	0·417	1·192	1·609	Nil	Nil
23	,,	1·395	1·812	0·203	25
20	,,	1·665	2·082	0·473	60
18	,,	1·901	2·318	0·709	90
16	,,	2·188	2·605	0·995	126
14	,,	2·560	2·977	1·268	160
12	,,	3·060	3·477	1·868	236
10	,,	3·753	4·170	2·561	325

TABLE 8.—BLAST-FURNACE COKE GAS.

Loss through Sensible Heat in Waste Gases at Varying CO_2 for Various Rises of Temperature.

Per cent CO_2	200° C.	250° C.	300° C.	350° C.	400° C.	Flame Temperature
	Loss %	Loss %	Loss %	Loss %	Loss %	C.
25·9	11·1	14·1	16·8	19·8	22·8	1,510
23	12·3	15·7	18·7	22·1	25·4	1,370
20	14·1	17·7	21·2	25·1	28·9	1,220
18	15·5	19·7	23·4	27·7	31·9	1,110
16	17·3	21·9	26·2	30·9	35·6	1,000
14	19·1	24·0	28·8	34·0	39·0	890
12	22·8	28·7	34·5	40·5	46·7	780
10	27·2	34·2	41·0	48·2	55·4	670

TABLE 9.—BLAST-FURNACE COAL GAS.

Composition Per cent		Calorific Value	
CO_2	7·3	CO	0·301 × 3,062 = 921
CO	30·1	H_2	0·073 × 2,613 = 191
H_2	7·3	CH_4	0·011 × 8,598 = 94
CH_4	1·1		
N_2	54·2		1,207 calories per cub. metre = 136 therms per cub. ft.
	100·0		

TABLE 10.—BLAST-FURNACE COAL GAS.

	1 cub. ft. of Gas	Oxygen Required	Products of Combustion CO	H_2O	N_2
CO_2	0·073	—	0·073	—	—
CO	0·301	0·155	0·001	—	—
H_2	0·073	0·036	—	0·073	—
CH_4	0·011	0·022	0·011	0·022	—
N_2	0·542	—	—	—	0·542
	1·000	0·213	0·385	0·095	0·542

Air required:

$0·213 \times 4·77 = 1·018$ cub. ft., carrying N_2 0·802

1·344

	Composition Dry	Wet	Theoretical CO_2 Dry	Wet
CO_2	0·385	0·385	22·3 %	21·1 %
H_2O	—	0·095		
N_2	1·344	1·344		
	1·729	1·824		

TABLE 11.—BLAST-FURNACE COAL GAS.

Composition of Waste Gas from 1 cub. ft. of Gas at Varying CO_2.

Per cent CO_2 on Dry Waste Gas	CO_2	H_2O	Air and N	Total Dry Waste Gas	Total Wet Waste Gas	Excess of Air	Excess of Air, per cent
23	0·385	0·095	1·344	1·729	1·824	Nil	Nil
20	,,	,,	1·550	1·93	2·025	0·20	20
18	,,	,,	1·765	2·14	2·235	0·41	41
16	,,	,,	2·025	2·41	2·505	0·68	68
14	,,	,,	2·365	2·75	2·845	1·02	100
12	,,	,,	2·825	3·21	3·305	1·48	147
10	,,	,,	3·465	3·85	3·945	2·12	210
8	,,	,,	4·435	4·82	4·915	3·09	306

TABLE 12.—BLAST-FURNACE COAL GAS.

Loss through Sensible Heat in Waste Gases at Varying CO_2 *for Various Rises of Temperature*

Per cent CO_2 on Dry Waste Gas	200° C.	250° C.	300° C.	350° C.	400° C.	Flame Temperature
	Loss %	Loss %	Loss %	Loss %	Loss %	C.
22·3	10·1	12·8	15·5	18·2	21·1	1,600
20	11·1	14·0	17·1	20·1	23·1	1,470
18	12·2	15·4	18·7	21·9	25·3	1,360
16	13·5	17·2	20·8	24·2	28·1	1,240
14	15·3	19·3	23·3	27·4	31·6	1,110
12	17·7	22·2	26·9	31·6	36·4	970
10	21·0	26·4	31·9	37·4	43·1	840
8	26·0	32·6	40·2	47·2	53·2	700

TABLE 13.—PRODUCER GAS.

Composition Per cent		Calorific Value			
CO_2	11·6	CO	$0·184 \times 3,062 =$	563	
CO	18·4	H_2	$0·26 \times 2,613 =$	679	
H_2	26·0	CH_4	$0·022 \times 8,598 =$	189	
CH_4	2·2				
N_2	40·0			1,431 calories per cub. metre = 162 therms per cub. ft.	
H_2O	1·8				

TABLE 14.—PRODUCER GAS.

	1 cub. ft. of Gas	Oxygen Required	Products of Combustion CO_2	H_2O	N_2
CO_2	0·116	—	0·116	—	—
CO	0·184	0·092	0·184	—	—
H_2	0·26	0·13	—	0·26	—
CH_4	0·022	0·044	0·022	0·044	—
N_2	0·40	—	—	—	0·40
H_2O	0·018	—	—	0·018	—
	1·000	0·266	0·322	0·322	0·40

Air required:

$0·266 \times 4·77 = 1·268$ cub. ft., carrying N_2 1·00

1·40

	Composition of Waste Gas Dry	Wet	Theoretical CO_2 Dry	Wet
CO_2	0·322	0·322	18·7 %	15·7 %
H_2O	—	0·322		
N	1·40	1·40		
	1·722	2·044		

TABLE 15.—PRODUCER GAS.

Composition of Waste Gas from 1 cub. ft. of Gas at Varying CO_2.

Per cent CO_2 on Dry Waste Gas	CO_2	H_2O	Air and N	Total Dry Waste Gas	Total Wet Waste Gas	Excess of Air	Excess of Air, per cent
18·7	0·322	0·322	1·40	1·722	2·044	Nil	Nil
17	,,	,,	1·57	1·892	2·214	0·17	13½
15	,,	,,	1·82	2·142	2·464	0·42	33
14	,,	,,	1·98	2·302	2·624	0·58	46
13	,,	,,	2·15	2·472	2·794	0·75	59
12	,,	,,	2·36	2·682	3·004	0·96	76
10	,,	,,	2·90	3·222	3·544	1·5	119
8	,,	,,	3·70	4·022	4·344	2·3	180

TABLE 16.—PRODUCER GAS.

Loss through Sensible Heat in Waste Gases at Varying CO_2 for Various Rises of Temperature.

Per cent CO_2 on Dry Waste Gas	200° C.	250° C.	300° C.	350° C.	400° C.	Flame Temperature
	Loss %	Loss %	Loss %	Loss %	Loss %	C.
18·7	9·5	11·9	14·5	17·0	19·7	1,680
17	10·2	12·8	15·5	18·3	21·2	1,570
15	11·2	14·1	17·2	20·3	23·5	1,440
14	11·9	15·0	18·2	21·5	24·8	1,370
13	12·7	16·0	19·3	22·9	26·2	1,300
12	13·6	17·1	20·8	24·5	28·2	1,220
10	16·0	20·0	24·2	28·6	33·0	1,060
8	19·4	24·4	29·4	34·6	40·0	900

One other Table, No. 17, is here added, by which the labour of calculation in making out the above tables is much shortened. This table gives coefficients for the different rises of temperature, which only require to be multiplied by the volume of the particular constituent of the gas to read directly the sensible heat.

For example, a gas consisting of CO_2=15 per cent, H_2O=2 per cent, air, N_2 and CO=87 per cent, at a temperature of 200° C. above atmospheric temperature carries sensible heat as shown thus:—

CO_2	..	$0{\cdot}15\times82{\cdot}8=12{\cdot}4$
H_2O	..	$0{\cdot}02\times74{\cdot}0=1{\cdot}48$
Air N_2CO		$0{\cdot}87\times62{\cdot}4=54{\cdot}2$
		1·00

68·08 calories per cub. metre $\times 0{\cdot}11233=7{\cdot}6$ therms per cub. ft.

TABLE 17.—COEFFICIENTS.

Degrees C.	CO_2	H_2O	Air, N, CO, and H
200	82·8	74·0	62·4
250	106·3	94·4	77·4
300	130·8	115·5	93·3
350	156·2	137·4	109·3
400	183·2	160·0	125·5
450	210·7	183·4	141·8
500	236·0	207·5	158·3

DISCUSSION BEFORE THE INSTITUTION, 22 NOVEMBER, 1917.

Mr. Sparks.

Mr. C. P. SPARKS: The paper deals primarily with gas-fired boilers, with gas, and how to handle it. I had hoped that the author would have devoted more attention to the preliminary stage, namely, how the gas is to be obtained, although he has alluded to the waste gases from by-product ovens and blast-furnace gas. The question of how the gas is to be obtained is of fundamental importance. To-day the major part of the electricity generated is produced by burning raw coal, and the whole of the valuable volatiles which could furnish by-products are destroyed by being burnt in the furnace. The chemical industry, which is one of our staple industries, is dependent upon these so-called by-products. It is recognized that it is a national necessity to stop this waste. At the moment we have two principal methods for the distillation of coal. We have first the coke production of the country, which is very important and increasing; in this case the coal is handled from the point of view of producing coke having certain characteristics for the iron and steel industries. The gas is a by-product as well as the volatiles which are saved, including sulphate of ammonia, and tar, oils, etc. Then there is the second method, where the primary consideration of the distillation is to obtain as much gas as possible, the coke, which is of poorer quality, being a by-product; sulphate of ammonia, tars, oils, etc., are again saved. Finally we have various products of low-temperature distillation where a new type of fuel is to be produced for household purposes, and here again gas with tars, oils, etc., will be by-products. Now are we to put our power stations near the coke-ovens and use the surplus gas; or are we to work in conjunction with the gas companies, in which case the coke would be used as the source for obtaining electric power; or are we to await the development of a new domestic fuel? In my opinion our problem is altogether different from either of these systems, and I believe that we should approach this question from the point of view of the power engineer. What we have in view is neither gas nor coke; we want to convert the heat units of the fuel into electricity in the most economical manner, and at the same time to save the volatiles as by-products. While in some cases we may work in conjunction with coke ovens, gas works, or the domestic fuel works, broadly speaking we have to solve our problem in an entirely novel manner. How is the position being faced? We have to-day under the Privy Council an important committee, the Fuel Research Board, which is going to examine the whole subject and look at it from the point of view of how the coal of the country can best be used for all the objects I have mentioned. In addition to that there are certain important commercial undertakings which are making their own investigations. I will just point out the limitations with regard to the production of electricity if we work only in conjunction with the coal distilled for coke manufacture. Coke manufacture for the iron and steel industries takes place primarily at the coal pits. Although the pits as the source of coal have attracted large industries to their particular neighbourhoods, in many cases there is great difficulty with regard to water for condensing purposes at the pits. In the present state of our art, having obtained our gas, the most economical method of utilizing it for electricity supply is to turn it into steam and use large

arks. turbo-alternators. Unfortunately, the absence of water severely cripples the gain we obtain from the possibility of getting this cheap fuel. In addition to the question of transmission from the pit we are faced with the fact that, owing to the absence of water facilities, we can only look for a comparatively poor vacuum from the use of cooling towers. Alternatively, if we work in conjunction with gas undertakings, these as a rule are comparatively near to the centres of distribution, and the association of electricity supply and gas undertakings would generally tend along the present lines of small centralized undertakings rather than in the now well-recognized direction of having a much larger area of supply and larger electrical undertakings in the future than we have had in the past. Thus the future of gas for large electricity supply undertakings is closely wrapped up in the working out of a process for complete gasification of coal, combined with saving part of the volatiles as by-products.

ouse. Mr. W. B. Woodhouse: The author's paper forms an interesting introduction to a subject of great importance to electrical engineers concerned with the generation of electricity, and he has brought before us the most important points in gas-firing. Fuller reference might have been made to the Bonecourt boiler * and to other recent interesting developments in gas-firing, as these emphasize the great importance of regulating gas and air pressure to obtain efficient combustion. As to the relative merits of gross and net heat value, I think the point is really this: are we content to use as the heat value a figure which will give in boiler efficiency a ratio of heat output to heat input which may exceed 100 per cent? If so, we shall take the net heat value of the gas; if not, we shall take the gross heat value of the gas; but so long as it is known which we have taken, I do not think it matters very much. On page 58 the author gives a table of calorific values. He tells us first that in this country "we quote the number of therms at 60° F. and 30 in. mercury column," and then in the table following he sets out therms per cubic foot at 32° F. It ought to be made clear in that table that both therms per cubic foot and calories per cubic metre are reduced to the same temperature. I should like the author also to verify the figure he gives as to the calorific value of ethylene, 1,724 therms per cubic ft., which according to most authorities is rather on the high side. I have had a considerable experience in the use of gas fuel and must disagree substantially with the author's estimates of the value of the surplus heat from coke ovens and blast furnaces; they are very rosy ones. The value of the surplus gas is only confused by the intermediate reference to the amount of coke and pig iron produced; the proper comparison is an answer to the question: What is the cost of coal to produce an amount of steam equal to that which could be produced from the surplus gas? To answer this question we need only know the quantity and the heat value of the surplus gas in each case and calculate the equivalent amount of coal required to raise steam. In my own experience of coke-oven working, the estimate of 6,000 cubic ft. of surplus gas per ton of coal is much too high; in many cases the surplus is negligible, and in any case a net heat value of 450 therms per cubic ft. is rarely reached. If one takes the surplus heat per ton of coke coked as being about 1/16th of the heat value of the coal, the estimate will be a reasonable one. On this basis the value of the surplus gas based on coal at 10s. per ton is $7\frac{1}{2}$d. per ton of coal coked, as compared with the author's figure of 1s. 3d. With regard to blast furnaces also, I think the figure is extremely high. One hardly regards as surplus gas in a blast furnace that which is used for blowing and for the stoves; the really important thing from the power point of view is how much gas we take off when we have carried through our process of producing pig iron, and the blower is an essential part of that. I have worked out what I consider to be a fair figure for average blast-furnace practice based on the heat in the gas, and on the author's basis of coke at 18s. a ton and coal at 12s. a ton the equivalent value of the surplus is 1s 6d. per ton of pig iron produced. That is a very different figure from the author's. Some people are fond of condemning our practice in this country, but as a matter of practice there are few ironworks where the surplus gas is not used. It may be that there is room for more efficient working. The author makes a very strong point when he says that producer gas, which in heat value is equivalent to blast-furnace gas, has not proved a success. It is very difficult indeed to get successful boiler-firing with a gas containing so much inert matter as producer gas and with such a low practical flame temperature, but the thing can be done, and I see no reason why it should not be done; it is gradually being done in our English works. With regard to his statements as to producers, I think it would be clearer if he gave the net efficiency of the producer. He assumes first of all an efficiency of 75 per cent; then he deducts the amount of heat required for steam-raising, which is a part of the process of producing gas. What one really wants to know is the total heat value of the surplus gas after carrying out all the processes necessary for working the producer. I should like the author to explain what he means by his reference to dry gas on page 61. If it is gas containing no suspended moisture but merely saturated, then I can understand it, though I should not call it dry; but if he suggests that the gas should be unsaturated, then it is a question in most cases as to whether the game is worth the candle. Undoubtedly if before we use the gas we reduce it to atmospheric temperature or below, we get more efficient burning, but we lose a certain amount of heat in cooling the gas, and to dry the gas we have either to spend money or power in doing so. I should like to know the author's view on that. I take it that by dry gas he means saturated gas with no surplus moisture. As to most of the points mentioned I think no one who has used gas can disagree with them. It is important to look after all of them, and it is also important to see that the boiler is designed with a sufficiently long gas path and that the pressure of the gas supply is proportioned to the amount of gas and to the design of the boiler;

Mr. Woodhouse.

* C. D. McCourt: "The Bonecourt Boiler," *Journal I.E.E.*, 1914, vol. 52, p. 724.

and it is a good plan to have recording instruments to tell us all these things. As a matter of experience, the introduction of recording instruments requires a testing department to maintain them. Where the undertaking is large enough to afford that, there is no doubt their use is very valuable.

Mr. E. W. L. Nicol: The author remarks that gaseous fuel is an ideal one; that being so, it is in my opinion too good a fuel for boiler-firing on a large scale. I refer to coal gas. The fact is that the surplus combustible residual of the coal carbonization and by-product recovery process is chiefly gas-coke; it always has been and in my opinion it always will be. The pressing need of the moment appears to be the development of a mechanically coke-fired boiler furnace for steam generation on a large scale. The furnace would be something quite different from the ordinary coal-fired one, because I have in mind the desirability of utilizing for the purpose of generating electricity not only the large quantities of sensible heat which are available at many large gas works, in the flue gases of the retort settings, but the incandescent coke itself. The coke usually is discharged from horizontal and inclined gas retorts at a temperature of something like 1,800° F.; the sensible heat it contains is about equal to 13 per cent of the heat used for carbonizing the coal and, except in isolated cases, practically the whole of this sensible heat is unavoidably wasted in quenching the coke. It is available for steam-raising if some practical means of using it could be devised. That would mean, of course, not only joint working of the gas and electricity-supply undertakings, but very close co-operation between them. It would mean that the steam plant and also the steam turbo-generators would have to be put down actually on the gas works or adjoining premises. The usual practice in many modern gas works is to transport the hot coke direct from the retort houses by means of a telpher line, the coke skip being lowered into a tank of water and the coke quenched in that way. It seems to me only a step further to dump the incandescent coke into suitably constructed boiler furnaces, in the same way as it is now dumped as required into the producer furnaces at gas works. The problem of gas-firing steam boilers on a large scale would appear to be formidable, but the author, I am glad to see, does not suggest the firing of steam boilers on a large scale with gas as fuel. New power stations contemplated nowadays are of the order of 100,000 kw., and taking the low figure of 30,000 therms per unit generated, I calculate that for a station of this capacity no less than 23,000,000 cubic ft. of producer gas would have to be transmitted per hour. The duct necessary to transmit that amount of gas at normal pressure would be of the order of one of the London railway tubes, or perhaps two or three of them. For a mixed gas of higher calorific power the problem would be only little less formidable, and the use of straight coal gas is of course out of the question, except perhaps in the few isolated cases where surplus gas of this description is available as a waste product.

Mr. H. W. Kolle: I propose to confine my remarks to the subject of blast-furnace gas-firing, as the company with which I am associated has some 300 to 400 boilers so fired, and we have consequently a good general experience of the results likely to be obtained in every-day work. In my opinion the statements of the author are too roseate. It must be remembered that blast furnaces are installed essentially for the production of pig iron, and that the gas itself is merely a by-product. Obviously, the gas should be utilized to the best advantage, but a great difficulty under existing conditions of working is that as soon as the gas is produced in the furnace it must either be used or wasted, and one problem is, how best to save and store the gas at present periodically escaping to the atmosphere. Outside of this, the chief obstacle to the economical utilization of blast-furnace gas is the constant variation of pressure on the gas main. Speaking generally, there are two methods of burning blast-furnace gas, i.e. in combustion chambers constructed entirely of firebrick, or in combustion chambers equipped with burners of the Bunsen type. In the former design, the gas and air enter separately through a number of ports or slots in the inner firebrick lining, and combine and ignite inside the chamber proper. In the latter case, the gas passes through a tube which is surrounded by one or more air pipes, and the gas ignites at the mouth of the Bunsen burner. In either case, the quantity of gas entering through a given orifice is determined by the pressure on the gas main plus the suction draught in the combustion chamber. The latter is reasonably constant, but if the pressure on the gas main varies, it is obvious that with a given aperture the quantity of gas entering the combustion chamber will vary materially. The air supply, however, is governed principally by the suction draught in the combustion chamber, which, as stated above, is practically constant, and with a variable gas supply and a reasonably constant air supply it is obviously exceedingly difficult in everyday work to adjust the ratio of air to gas to anything approaching theoretical conditions. Further, it must be remembered that in blast-furnace gas we have some 30 per cent of combustible mixed with 70 per cent of incombustible, with the result that the oxygen in the air has to seek out the combustible, and to do this effectively a good deal of excess air is required. For this reason I consider that the author's figure of 25 per cent excess is altogether too optimistic for everyday working conditions. A more general figure would be in the vicinity of 100 per cent excess air, and even this would be considered good everyday practice. When starting a boiler to work, one has to see that the air supply is adequate for the maximum quantity of gas that can pass with the maximum pressure that can obtain in the blast-furnace main, otherwise secondary combustion would result from time to time and trouble arise in the flues and chimneys. In our experience, boilers fired with blast-furnace gas are usually in the charge of a water tenderer, and whilst the air supply may be occasionally varied, this does not happen very frequently. In reality, the water tenderer does not have the necessary facilities to enable him to obtain the best results. Very few blast-furnace installations have any apparatus for recording continuously the amount of CO_2 in their waste gases; in fact it is not an unusual thing to find at such a works that they have no appliances at all for

r. Kolle. readily testing the amount of carbonic acid gas in the gases leaving a boiler. It is by no means so easy to carry out a really accurate efficiency test on boilers fired with blast-furnace gas as some people imagine. I know of only one or two installations where any plant is installed for adequately cleaning blast-furnace gas. With a dirty gas the quantity passing obviously cannot be measured through a meter, and one has to rely on Pitot tube readings, and anyone who has endeavoured to measure velocities in this way knows that it is very tricky, and that throughout the diameter of the tube, particularly if of large size, fluctuating and variable readings are obtained. To calculate the volume, it is also necessary to determine the density of the gas, so that if any members are interested in installing power stations at blast-furnace works they will require to make further investigations than the paper indicates, and they would do well not to base their calculations on too high a thermal efficiency. I mention this specially, because the paper rather assumes two things. One of these is a reasonably constant gas pressure, and I think there is hardly an installation in this country where practical means exist of regulating the pressure on the blast-furnace mains. The second point is the cleanliness of the gas. It is perhaps an open question whether with the appliances at present on the market very much gain results by cleaning the gas for boiler firing. To do this with either the Thiesen wet process or the Halberg Beth system of dry cleaning, entails a considerable loss of sensible heat. The ideal system would be one in which the gas was cleaned and dried at the temperature at which it leaves the blast furnace itself, as it could then be used with its sensible heat unimpaired. One point on which I fully agree with the author, is that not nearly sufficient attention is paid at blast furnaces, or indeed at electric light installations, to the training and knowledge possessed by the man who has to look after the plant. Indeed, in my opinion electric supply authorities are extremely mean and short-sighted in this particular. How many installations are there where upwards of a quarter of a million tons of coal are burnt per annum, and where the man in charge of the boiler-house plant is paid £250 to £350 a year? A minute or two's calculation would prove that one could afford to pay a really highly-trained engineer £1,000 a year, and at this figure he would pay for himself many times over. In most installations where coke-oven gas or producer gas is used for boiler-firing purposes, the conditions are very different from those at blast furnaces. In the great majority of producer installations the gas is generated for the purpose of ultimately burning it, with the result that a regular pressure can be maintained on the distributing mains. In such cases the gas is clean, and burners can be designed to give quite a high efficiency of combustion. We have had tests carried out where even with producer gas purposely saturated with water vapour, efficiencies of 72, 73, and 74 per cent have been obtained on the boiler alone, working without an economizer. With coke-oven gas, a similar high efficiency can also be secured when working under proper conditions.

Paton. Mr. J. D. Paton: One thing I have noticed is the author's accentuation of the value of carbon monoxide as against the hydrogen content. It is a peculiar Mr. Pato coincidence that the modern trend in distillation is the elimination of the hydrogen content in a liquid hydrocarbon form. I would also suggest to the members that they should consider the emissivity values of the various flames produced by the combustion of the different gases, noting that the hydrogen produces its colour in the blue zone and carbon monoxide in the red zone of the spectrum, which defines their capacity for radiation or heat transmission on a radiant-energy basis. With regard to the material of construction, I have been forced through investigations of the stability of materials to consider also the transmission of heat through alloys. Given a pure plate of one metal the transmission value is definite, and given another metal plate of a pure nature it has a fixed value, but I am convinced that by a combination of the two into an alloy there is neither a true average nor a constant value. I hold that the Le Chatelier currents established in the bimetallic condition have some detrimental property on heat-transmission values, that the deterioration of metal and lower conductivity is a function of this influence, and that this is the field for investigation by electrical engineers. With reference to pyrometers, I have a point of dispute with the author as I have installed one of the largest installations in the world for a chemical combine where they had every means of testing on a chemical basis, but they established their results on a pyrometric basis, having found that to be easier and more accurate. The design for a boiler should be on a thermal basis, but in the past the boiler-house has been controlled by a shovel and a pressure gauge which had small relation to the thermal basis. In a correct design the system consists of various zones with different absorption capacities; and when once the maximum efficiency has been established by a combination of chemical and pyrometric observations a fixed temperature can be defined for the entrance and exit on any zone, and the installation can be run on this basis. This has been established by Mr. Wood at the Bolton electricity works. Regarding the statement of one speaker that there would always be the production of coke as the beginning and end of the question, I beg to differ, and I will pass round a sample of coal one-half thousandth of an inch thick showing the natural oils in position and also grades of material which could never be used for the coke at present demanded by the various industries. With regard to condensing water for "mother stations," the bulk of our coal-fields touch the sea-board, and our inland fields with their submerged surfaces such as Wigan would provide enough water on the surface for the national scheme. The Doncaster field will one day become another inland sea if present mining practice continues, and if we proceed cautiously enough might yet supply condensing water for the North-East "mother station." In answer to Mr. Sayers (page 80), I may state that in the United States I acted as research engineer for the late Mr. George Westinghouse on gas-producer work, and the first type of scrubber which we used for cleaning the gas was on the lines suggested by him.

Mr. W. R. Cooper: I value the paper from two Mr. Coope

points of view. First of all it is an analytical paper; secondly, there can be no question that gas-firing will come in the future and we must be prepared to deal with it. But I am sorry the author does not give us any efficiency results. If one looks up tests of gas-firing one generally finds the steam that is obtained, the heating surface, an analysis of the fuel gas, and the calorific value, but the chances are one never finds the quantity of gas used. That apparently is due to the fact that, so far, gas-firing has been chiefly applied to gases which are by-products; but if we are to go in for the carbonization of coal on a large scale in the future, that will no longer be the case, and then the efficiency of gas-firing will become very important. We must then have further results; we must have the quantity of the gas, and we must know how it is measured. If the steam is given us to an accuracy of, say, 2 per cent it is no use having the quantity of gas to, perhaps, 10 per cent of doubtful value. With regard to boilers, of course the coal-fired boiler depends upon two principles: first, radiation, and second, conductivity from the gases. The radiation is very important, but in the gas-fired boiler that is mostly lost, and therefore the problem of obtaining all-round efficient results is much more difficult. In the case of the Bonecourt boiler an attempt is made to obtain radiant heat. No doubt the high output per square foot of heating surface is largely due to the fact that radiant heat is obtained. This view is borne out by the fact that the part of the flue (say one-third of the length) near the gas jet is much more active than the remainder; i.e. the activity does not fall off merely in proportion to the fall of temperature. I notice the author compares the Lancashire boiler with the Bonecourt boiler on a low steaming rate, which seems scarcely fair. It seems to me that progress in the future will be obtained by getting more radiant heat in gas-fired boilers than has been done hitherto, because it is a more efficient way of getting heat into the water. With regard to producers, attention has already been drawn to the figure of 75 per cent efficiency. To start with, that is a high figure, regarded merely as the ratio of the heat units obtained in the gas to the heat units in the coal. We cannot deal with a dry coal merely, but must take it as fired, and apart from that there is the effect of the steam, which has a very marked effect indeed and cannot be neglected. I think that designs in the future, from the point of view of improving the efficiency, will depend largely on the reduction of the amount of steam used, as has been done to some extent in the Moore producer, and I think something could be done on the lines of the suggestion of Mr. Eldred mentioned by the author. It has been suggested in the discussion that in future we may be using coke as well as gas for the boilers. I would point out that, commercially speaking, the future of carbonization must depend a good deal upon the value of the resulting by-products. If we merely use the gas obtained by carbonization, and also use the resulting coke, we get from the carbonization 20 to 30 lb. of ammonium sulphate, which is one of the most valuable by-products, out of a possible 90 lb. or more per ton. A large proportion of the nitrogen remains in the coke which is used for firing the boilers. In other words, a large part of one of the most valuable constituents is consumed. There is also another point, namely, that if we use that hard coke in producers in order to get ammonium sulphate so as to recover the nitrogen, difficulties are experienced. If one goes in for low-temperature coke there is a larger amount of volatile, and therefore it can be used to better advantage in recovery producers. I therefore think low-temperature carbonization and the total gasification of coke will have to be considered for power purposes.

Mr. Cooper.

Mr. W. H. PATCHELL: I think the paper would be still more valuable if the author would give us references to the allusions he makes. I agree with the last speaker that in some respects the author has overdrawn his estimates. If instead of giving us an assumption the author had given us actual cases from his practical experience some of his figures would have been very different. Mr. Kolle has dealt with the blast furnace. If the author had quoted actual figures from coke-oven practice (page 59), instead of having stated 96,500 tons of steam per annum he should have quoted about 66,000 tons per annum. Anybody who thinks of obtaining 96,500 tons spare steam from such a coke oven must look for trouble when he has to substantiate his guarantee. Mr. Sparks hit the nail on the head; some people are out to sell coke and others are out to sell gas. Many of us will not take anything but a fire that we can poke, whether it gives smoke or not, so a certain amount of low-temperature coke will always be wanted. The matter has, however, to be looked at broadly and commercially, and, from the point of view of this Institution, we have to see whether coal cannot be turned into electricity more economically without prejudice to anything we have done at present. I think the matter will centre round the question of by-products. There is one obvious disadvantage about coke; unless the coal is washed there is a large percentage of ash. It is also difficult to transport on account of the large space occupied. If we could deal with the coal in a producer economically it would solve the problem. At the top of page 60 the author says "with the latest by-product recovery producers the steam necessary for producing by-products has been reduced to the amount necessary to drive the blowers, etc." At the bottom of the same page he refers to the Moore producer. Will he tell us more about it; the case is not proved by that bald statement. If we turn back to Humphrey's classical papers we find that he allowed in his paper before the Institution of Mechanical Engineers (December 1900) $2\frac{1}{2}$ lb., and in his paper before the Institution of Civil Engineers (December 1912) 2 lb. of steam per pound of fuel. Later practice has reduced the quantity to $1\frac{3}{4}$ lb. of steam per pound of fuel. Taking the author's figure as the amount necessary for the blowers, ordinary blowing does not take more than 1 horse-power per ton of fuel, say 30 horse-power for a 30-ton plant, and, allowing 40 lb. of steam per horse-power-hour, we should only have 0·4 lb. of steam per pound of fuel gasified, which will not satisfy the producer because the temperature has to be kept low, otherwise the ammonia is dissociated and a most valuable by-product is lost.

Mr. Patchell.

r. atchell.

How does the author propose to make up the difference? The Moore producer has a jacket certainly, but that jacket will not help us very much. On the question of boiler radiation the author quotes 1½ per cent. That is rather lower than is generally accepted. What does radiation include? In many boiler tests we find that radiation is taken as the other losses which we cannot usually measure. Take Stott's tests.* I suppose no man ever tested more carefully than he, and his test showed 8 per cent radiation. It would be useful if the author would give us a figure to substantiate his 1·5 per cent. Why is the author so modest in his references? Those who wish to use this paper might well turn to the *Electrician* of 15th June last where they would find several gas burners described—Mr. Hunter's burner, the Cumberland, the Wellington and others—and there is a reference to Mr. Humphrey's paper,† on the plant of the South Staffordshire Mond Gas Company at Dudley Port where gas-firing was used for Climax boilers. Later, Lancashire boilers were added with alternative arrangements for mechanical stoking and gas-firing. One of the earliest gas-firing installations was described in Mr. Humphrey's classical paper ‡ on the Mond plant at Winnington.

ghfield.

Mr. J. S. HIGHFIELD: It is well known, and the discussion has emphasized the fact, that there are large quantities of heat sources scattered rather broadly in different parts of the country, particularly in the manufacturing districts. The examples we have had are the coke-oven plant, the blast-furnace plant, and other sources like the hot coke in the gas works. It is quite clear that as electrical engineers one of our first duties is to collect all these forms of heat and turn them into electricity. At present, so far as we can see, electricity offers by far the best way of making direct use of these sources of heat. But when this has all been done we have still the problem of generating electricity in very large quantities, because these waste products are not going to supply more than a proportion of the total amount of electricity required. We have still the problem of using coal not directly in boilers but in some indirect way allowing for the collection of residuals, for generating the bulk of the electricity for all purposes. The known means of doing this are either by distilling the coal, as is done in gas works—it may be done at high or low temperatures according to what by-products pay best—or by using producers of the ordinary Mond type. The difficulty is to get figures which will show that the method will pay. I will submit a few figures, because in considering the question of generating electricity by the use of gas my difficulty has always been to get accurate figures from running plant. If we take a moderate-sized electric plant with turbines of 2,000 or 3,000 kw. capacity we shall do very well if we produce about 900 units per ton of coal. Taking the price of the coal at 20s. per ton, the fuel cost for 900 units is 20s. To generate 900 units by gas-fired boilers, first of all using the coal in producers to make the gas and then burning the gas in boilers, we shall want at least 1¾ tons of coal. That is equal to 25s. I am assuming that we get from the coal the by-product, sulphate of ammonia, and a certain amount of tar the value of which is probably negligible. The ammonia, I think, may be taken as 10s. net for the 1¾ tons of coal. So that from the 25s. we deduct 10s. and get a net cost of fuel of 15s., compared with 20s. for coal burnt directly in the boiler. That leaves 5s. over to pay the interest on the cost of the gas-producing plant. I think it is just about sufficient, so that although we gain the ammonia the financial position is not in any way improved. Taking another way of using the gas, namely, instead of putting it into the boilers and using a steam turbine, sending it direct into a gas engine. A good modern gas engine of about 1,000 h.p. with producer gas would generate 900 units with about 3/5 ton of coal. That is worth 12s. We get back at the same rate of recovery for by-products 5s. net from the ammonium sulphate, and the net coal cost is 7s., compared with 20s. for the steam and 15s. for the gas-fired boilers. I put these figures forward as approximate only, but they are an example of what we want. I hope the author can give us them more accurately. Mr. Highfield.

Mr. A. H. DYKES: Practically the whole problem of the production of electricity in the future is bound up with this question of the utilization of gas for boiler-firing. First of all, there is no doubt we shall have to utilize waste gases from coke ovens and blast furnaces, as we are doing to a large extent already, more particularly on the East coast. Then we shall have to consider the larger question of the capital stations where we are not merely utilizing the waste heat from existing blast furnaces, but where we have to put down new stations especially for generating power in large quantities. There, again, the decision will not be left altogether to us; it will have to be decided by us in conjunction with the chemists and the metallurgists. The power stations of the future will be not merely for generating electricity, but a combination of a chemical works and a power station. The form in which we get the gas will, I think, be prescribed for us to a large extent by our partners in this work, and it is necessary that we should consider how we can best use the various types of gases with which we may have to deal. I hope one result of the paper will be that those who have had experience with gas-fired boilers will come forward and give us actual figures of results. There are a number of waste-heat stations in the North and we should like to know from the engineers in charge what their efficiencies are, what type of boilers they are using, what they have done to modify those boilers, and what is the water evaporated per ton of coke or iron produced. Probably the majority of the boilers which have been fired with gas are boilers which were installed originally for coal-firing, and which have been adapted. One cannot expect to get as good results with them as with boilers specially designed for gas-firing, and I think the large boiler-makers of this country will have to give us boilers adapted for burning different types of gas. There are one or two other points which must not be overlooked. There are subsidiary advantages of gas-firing over coal-firing. With the Mr. Dykes.

* H. G. STOTT: "Power Plant Economics," *Transactions of the American Institute of Electrical Engineers*, 1906, vol. 25, p. 1.

† *Proceedings of the Institution of Civil Engineers*, 1912–13, vol. 192, p. 1.

‡ *Ibid.*, 1896–7, vol. 129.

former—taking the electrical production side of it—because I presume that the converting of coal into gas will be done by the chemical side of the combined works—once we have got the gas the labour of firing our boilers is going to be considerably less than when using coal direct. We are going to use less manual labour all round and we can therefore afford to pay considerably more for skilled chemical and engineering supervision in using the gas when we have got it. As has been said to-night there is a tremendous amount of waste through not having sufficiently skilled men in charge. The best way to utilize the gas will be one of the most important questions in big power stations of the future, and as we are reducing the charges for labour in firing boilers we can afford to spend considerably more on the scientific side. Again, considerable saving will be effected by abolishing the mechanical stokers, the clinker plant, and the plant dealing with the ashes, and I should like to see some figures showing the difference in the cost of upkeep of the boilers when gas-fired and when fired with coal.

Mr. C. P. Taylor: There are two commercial considerations which are perhaps worth a moment's attention. Several speakers have referred to the efficiency of the producers given on page 60 and I certainly think the figures require some substantiation, especially with reference to the amount of steam necessary. Taking the author's figures as they stand, however, the 75 per cent gross efficiency in the producer is reduced to about 70 per cent as the net efficiency of the plant as a whole. That means that 30 per cent of the heating value of the fuel is being definitely thrown away. Looking at the combination of gas producer and boiler, the only justification for throwing this 30 per cent away is the recovery of by-products. Now we are witnessing a very marked rise in the price of fuel, and we have to bear in mind that as the value of this 30 per cent increases it will be less advantageous to adopt a combination of producers and boilers for steam-raising unless the price of sulphate of ammonia increases proportionately. In other words if the price of ammonia remains fixed at about its pre-war value, then the higher the price of the coal, the less is it going to pay to "gas-fire" in order to make steam. Some years ago we used to hear of cases in which the whole cost of the fuel used in a gas-producer plant was paid for by the by-products recovered, but I do not think we shall get that condition of things to anything like the same extent in future, and I am afraid it is going to upset many calculations we used to make before the war unless the price of coal decreases, which I am afraid we cannot hope for. My second point is this: in discussing this subject, I suppose what most of us have in mind is large power stations for the distribution of power electrically. I had occasion recently to look into quite a small proposition for distributing power for units of about 500 h.p. over a few miles, and it seems to me impossible to justify the use of electricity at all if we have gas, because we can much more easily and cheaply distribute the gas. I know that this is rank heresy, but if we are going to make gas we can transmit it very much more cheaply as gas, provided we are prepared to use a gas engine at the other end—and for units of moderate size this is now quite feasible. By this means we save considerable capital expenditure and big generator and motor losses, and I think it is very questionable whether if once it is decided to make gas from producers for power purposes, we can in many—if not in most—cases justify distributing it by electricity instead of by the gas itself.

Mr. L. B. Atkinson: Many of the speakers appear to be resting their cases for the gasification of fuel on the recovery of sulphate of ammonia as the by-product, and I think they are rather making a mistake in doing so. I think the by-products which are most likely to be important to us in the future are the tars and oils from which chemicals of that type can be produced, as I think we electrical engineers in particular must understand that we are going to destroy the sulphate-of-ammonia market ourselves. What is sulphate of ammonia used for? We do not eat it directly; we use it as manure, and as a matter of fact it is not useful as a manure till it has been turned into a nitrate by the action of bacteria in the soil, and we are now working on the actual production of nitrates direct by electrical processes. Sulphate of ammonia, which used to be £9 per ton, has since risen to £12 and £16 and even higher, but I believe it is claimed that we shall make nitrates from the atmosphere for £2 or £3 per ton, and I do not think anybody will ever buy sulphate of ammonia for agricultural purposes if he can get nitrates at the same price per unit of nitrogen. I think that plans for the generation of electricity and calculations which are based on sulphate of ammonia as the by-product will lead us to very great mistakes.

Mr. H. M. Sayers: With regard to cleaning gas, I would ask the author if any attempt has been made to clean blast-furnace gas by what I may call centrifugal methods, that is to say, by making the gas pass through a whirling chamber so as to deposit the dust by the effect of density.

Mr. H. W. Firth (*communicated*): The author mentions the problem of cleaning blast-furnace gas for use in steam boilers. This appears to be a matter of very great importance, not only in connection with the question of the use of gas for firing boilers, but also more particularly if the gas is to be utilized in gas engines. A considerable amount of information has been published in American technical papers, more particularly in two papers read by A. F. Nesbit and Linn Bradley before the American Institute of Electrical Engineers,* from which it would appear that a great deal of research has taken place in America on electrical precipitation, and that the results as applied to the cleaning of blast-furnace gas are considered to be hopeful. It will be very interesting if the author can give some information as to whether anything of this kind has been attempted in this country and, if so, what the results have been.

* A. F. Nesbit: "The Theoretical and Experimental Consideration of Electrical Precipitation," *Transactions of the American Institute of Electrical Engineers*, 1915, vol. 34, p. 405.

L. Bradley: "Practical Applications of Electrical Precipitation and Progress of the Research Corporation," *Ibid.*, 1915, vol. 34, p. 42.

Hunter. Mr. T. M. HUNTER (*in reply*): In the first place I wish to express my gratification at the way the paper has been received, and at the discussion which it has provoked. The paper was written especially for engineers who have to specify gas-firing plant, and for engineers who have to run such installations. Going to various works I have found an ignorance on the subject which seems appalling, compared with the great amount of knowledge that engineers have of the many other subjects with which they have to deal.

Mr. Woodhouse questions the value put upon the surplus gas from coke-oven and blast-furnace plants, saying that only the amount of gas available for generation of outside power can be considered as surplus gas, after all the power for the running of the plant has been provided. This is quite correct, but it misses the argument in the paper. All the gas from these plants which is available for boiler-firing purposes is here treated as surplus gas. From the gas-firing point of view all that gas must be burned in the most economical way whatever happens to the steam raised by its means; so that the figures in the paper are justified as examples of what may happen in certain plants. With regard to the difficulty which he finds in burning producer gas, as compared with blast-furnace gas, reference to the tables in the Appendix will show that the flame temperature of producer gas is (at least in some cases) higher than that of blast-furnace gas, while the dilution with inert gas is less in producer gas.

Mr. Kolle has spoken about blast-furnace gas under varying pressures. The tendency in this country is now to clean gas. A number of plants are even being installed during the war. If there is a cleaning plant there is not the same great fall and rise in gas pressure, but the pressure is more uniform. I have the figures of very many tests made in America on firing uncleaned blast-furnace gas. The ordinary efficiency in well-managed boilers fitted with gas burners, using uncleaned gas at constantly varying pressure, is from 65 to 67 per cent, which is an excellent result. The amount of excess air used is in few cases over 25 per cent, and is often less. Mr. Kolle's figure of 100 per cent excess air is, however, quite a moderate figure for the case of boilers which are not fitted with suitable gas burners—where the efficiency is often under 50 per cent. In most plants the steam lance is used twice a day to blow the dust off the boiler tubes. The chemical properties of the dust are very important. Possibly American dust is easier to blow off the tubes than British dust. I was recently in a boiler where the men were actually removing the dust with hammers—chipping it off—and there, apparently, the dust crystallizes on the tubes in a chemical rather than a mechanical fashion. In such a case it is necessary to clean the gas before a good efficiency is possible. When the dust is of such a nature that it can be blown off, a cleaning plant would not be a paying proposition.

One point with regard to cleaning gas is that, if cleaned gas is used, economizers are possible. Further, there is no reason for having scrapers in these economizers, so that the latter can be entirely built in and be free from air leakages. Such economizers would be much cheaper and more efficient than those for coal-fired boilers. Mr. Hunter.

Mr. Paton has spoken rather strongly about the use of pyrometers. It is difficult to persuade engineers to install these, because they seem to be so costly. It is not realized that the results attained soon pay for the cost, on account of the speed and accuracy with which readings are made.

Mr. Cooper has asked for the results of tests. Efficiency tests with gas-firing are so open to question on account of the difficulty of measuring the gas, that no such results have been included in the paper. With the types of boilers in use at present, and with boilers and settings in good order, superheaters and economizers being fitted, the working efficiency which we should maintain is 85 per cent with coke-oven gas, and about 80 per cent with cleaned blast-furnace and producer gas.

Mr. Patchell has put together two different paragraphs on page 60, one mentioning the Moore producer and the other the reduction in the quantity of steam which must be supplied to modern producers from the outside in order to make the sulphate of ammonia. I take no responsibility for these figures, but have simply gone upon the statements of producer makers. What an engineer must do is, when sending an inquiry for a producer, to obtain a guarantee of the amount of free, surplus steam which can be raised per pound of fuel put into the producer, after all the necessary steam has been returned to the producer. In that way an engineer can discover whether gas production for steam-raising purposes is a commercial proposition or not.

I agree with a remark which has been made to the effect that it is the business of gas engineers to generate the gas and that electrical engineers should only be called upon to use the gas and to pay for it. As to the price which electric power stations could afford to pay for gas, the case of a modern Lancashire power station is taken. There, 2·24 lb. of coal of 11,000 therms per pound are burned per kilowatt, and this fuel costs 18s. per ton. Assuming that the boiler efficiency is 75 per cent, the station would pay exactly the same for fuel per kilowatt if it bought town's gas of 500 therms per cubic foot net value at 5d. per 1,000 cubic feet, and burned this gas at 85 per cent efficiency; or if it bought coke-oven gas of 450 therms at $4\frac{1}{2}$d. per 1,000 cubic feet, or if it bought by-product producer gas at 1·32d. per 1,000 cubic feet of gas of 140 therms and burned it at 80 per cent efficiency. These figures take no account of the saving in labour and in maintenance charges on the plant if coal-firing were stopped. If town's gas only partially purified were used to fire electric power-station boilers in the summer months when the demand on the gas works is low, it could be bought at a very cheap rate. It would be quite reasonable that the gas department should charge the electricity department nothing for capital charges, but only a rate to cover a little more than the cost of producing the gas. The cost of the installation on the boilers, for burning the gas, is very small, and such an installation can easily be arranged so that it does not interfere with the mechanical stoking

Hunter. arrangement on the boiler fronts. On these lines even town's gas might well be found to be a payable boiler fuel.

I must thank Mr. Winstanley for his contribution at the Manchester meeting (page 84). By its aid I have been able to add to Tables 4, 8, 12, and 16, a column giving the flame temperature for each different condition. These figures add great force to the remarks in the paper, and show even more clearly the urgent necessity for having combustion under the most perfect conditions possible. They also help to explain the difficulty found in some plants, in burning blast-furnace and producer gas. The engineers running the plants tell us that the poorer the gas the more air it needs for combustion, whereas these tables show exactly the reverse. Table 8 shows that blast-furnace gas with 10 per cent CO_2 in the waste gases has a flame temperature of only 670° C. As CO only ignites at 600° C. it will be seen that this gas will hardly burn under these conditions—and yet 10 per cent CO_2 is not an uncommon reading with blast-furnace gas-fired boilers. Mr. Hunte

Manchester Local Section, 27 November, 1917.

Paton. Mr. J. D. Paton: I have already taken part in the discussion in London (see page 77), but I should like to ask the author to explain why a certain colour of flame gives the maximum value of evaporation. I think it will be found to be due to the fact that the flame is produced in a minimum distance, with a maximum value in the red zone, which is the zone whence we get the maximum radiant energy.

laston. Mr. T. R. Wollaston: Electrical engineers are fully alive to the fact that by-product recovery with gas-fired boilers must come, and valuable contributions have recently been presented by them to this and other societies on the subject, but they, and also the chemists, appear to me to find it difficult to co-ordinate admitted technical facts with actual conditions. Their experience, wide as it is, does not cover the connecting link. The author has succeeded, however, as an industrious pioneer, in the branch upon which we are most ignorant. I have only one criticism to make, namely, that the author, sure of his facts so far as they go, has not driven them home sufficiently. Coke ovens, blast furnaces, and producers are mentioned and their possibilities clearly set forth, but the essence of the paper, so far as electrical engineers are concerned, is too gently set forth in the third paragraph on page 59. Gas is a valuable by-product from coke ovens and blast furnaces, and should certainly be used for the production of cheap electricity, but it is inadvisable to dabble in incidental by-products on a small scale. Therms should be the first consideration. Taking the author's example of coke ovens, those 96,000 tons of steam are only sufficient for a toy substation. If we are going on such lines for the full electrical demands of the country, what are we going to do with the surplus coke? The same argument applies in every proposal for low temperature distillation. Electrical engineers controlling industrial costs want to consider therms first. If they can get a by-product rebate afterwards, they will be glad enough, but they must not be hampered by subtleties of supply and demand or variations in the chemical market thereby set up. To bring home better what I mean, the author's 6,000 cubic feet of gas per ton of coal represents 2,700,000 therms. The same coal can be gasified to give 17,000,000 therms, or six times the amount of electricity, and the by-products, among which coke and coalite will not be included, will probably aggregate equal or greater value. The author has outlined the limitations hitherto of recovery producer plant. He has also foreshadowed the lines of development, not as well as his knowledge would allow, but as well as definite and proved results which at present exist carry him. I admire his reserve and will for similar reasons leave this point. In the application of gas to boiler firing, the author, who speaks probably with as wide an experience as any other British engineer, may have shocked some members by recounting the low efficiencies at which firms have been willing to work for years. I hope also his figures of potential saving will shock them. He appears to have derived all his experience from normal Lancashire and water-tube boilers, and very clearly indicates their limitations under gas firing. There is only casual reference to the only essentially gas-fired boiler, the "Bonecourt." I have perhaps seen more of this boiler than the author has. While I do not think it can ever be a practical boiler, I think it has paved the way towards success. Two or three references in the paper imply that gas-fired boilers should work at 80 per cent efficiency. The Bonecourt boiler works at over 90 per cent. I am satisfied that when the problem is properly tackled by skilled boiler-makers we shall reach at least 85 per cent. This with a producer efficiency of 70 per cent (which will also be consistently obtained) will give substantially 60 per cent all-round efficiency, equal, I dare say, to what some electrical stations are now working at without by-products. I think it will be agreed that modern direct-fired boilers are designed specifically around the furnace, and my belief is that gas-firing will never come into its own until they are designed around gas burners, though the later designs of "Babcock" and "Stirling" boilers come nearer to the gas-man's ideal. There is one thing I have not been able to understand. The author speaks of using gas for firing with a surplus over the theoretical amount of air of 20 per cent. I gather he is suggesting that because gas is often somewhat irregular, it is necessary to have that extra amount to deal with that irregularity. I have carried out, however, a series of tests on gas-fired Lancashire boilers with producer gas and with Bunsen burners of a type which I believe the author has since improved—and I am perfectly sure of the gas analyses. They were made by a most competent man. The tests lasted for nearly a week and we got an average of 17 per cent CO_2 in the chimney gas, never any carbon monoxide, and I believe never more than 3 per cent excess oxygen. Mr. Wollaston.

Cramp.] Dr. W. Cramp: It is well to discriminate between the two main cases that arise in connection with the gas-firing of steam boilers, viz. (*a*) the adoption of gas-firing to make use of gas hitherto thrown away, and (*b*) the adoption of gas-firing with the object of using the coal to better advantage and of avoiding the production of smoke. It is the second case to which I wish to refer particularly, and this involves the use of a producer for gasifying the fuel. There are two main types of producer used in connection with boilers, namely, that type which is entirely apart from the boiler, and that type which is an extension of the boiler. The paper does not touch upon the second proposal at all. The two cases are very different. It is a matter of common experience that it does not pay to make use of a producer with a recovery plant for less than 750 h.p. But in many small plants coal ought to be burnt more economically, and less smoke should be produced. For such cases a producer attached to or forming part of the boiler is a possibility that should not be lost sight of. These producers cannot work with by-product recovery, but on the other hand the heat required for carbonizing is not lost. One form (the Mills type) has been successfully built, and has shown in connection with Cornish boilers a considerable economy in the consumption of coal per pound of steam.* The author's opinion upon such plants, and upon the question of the use of gas-firing for small installations, would be of very great use to us in Lancashire where there are so many independent boiler plants consisting of one, two, or three 30 ft. by 8 ft. Lancashire boilers. Where by-product recovery is aimed at, it is as well to remember that the gas-firing of boilers leads to no economy in the amount of coal required per pound of steam. On the contrary, the object is to get as much valuable material as possible from the coal apart from heat units, and only to burn that part which cannot be otherwise used. For a given quantity of steam this system calls naturally for more coal than that required by direct firing, so that if the future price of coal is determined to any extent by shortage of labour, matters will not be improved by the general adoption of gas-firing. The author touches upon the well-known fact that the by-product producer hitherto has had to use a large proportion of the steam which its gas raises for enabling the by-products to be recovered. He mentions the Moore producer in this connection and I would ask him to give us a few figures with respect to the statement at the top of page 60 that "the steam necessary for producing by-products has been reduced to the amount necessary to drive the blowers, etc." Is it not true that the Moore producer is still in the experimental stage? In some of the tables the author confuses the issue by failing to give the temperatures; for instance, in the table on page 58, and in other cases on page 60. The temperature should be stated because, as he himself says, the losses due to sensible heat may be considerable. He very properly draws attention to the loss that occurs due to the fact that the whole of the hydrogen in the coal has to be oxidized, producing water which must be kept above the temperature at which it condenses. It is evident that if we could only have an economizer which would stand the action of the water condensing upon its tubes, the temperature of the flue gases could be reduced and much more heat could be taken out of the flue gas. Why has that proposition never been properly attacked? The economizer tubes are attacked by the condensed water because it is acid; but there are plenty of metals in use in chemical works and other places which will stand strong and weak acids of the nature of that produced from boiler flues. Why then can we not have an economizer made of such a material as will enable us to recover this very important part of the heat at present thrown away? On page 60 the author refers to Lancashire boilers raising 8,000 lb. of steam, but does not give the size of the boiler nor the time in which this weight was evaporated. I am not sure whether he is aware that there is a dry process of cleaning gas by which tar and dust may be taken out with very little lowering of the temperature. It consists of a specially constructed cyclone which with proper velocity will take out 98 per cent of the tar fog in the gas. The pressure required for such a separator is very small. Why then can it not be used in connection with producer and furnace gas? It should enable a large percentage of the sensible heat in the gas to be saved, while still getting rid of the dust which interferes with measuring instruments and with the use of certain burners. Dealing with the abstraction of heat from gases, I do not know whether the author is aware that baffles have been employed in ordinary coal-fired boilers. Brick baffles have been built at right angles to the flues and have increased the velocity of the flue gases, causing them to sweep the boiler plates and thus increase the amount of heat abstracted from the gas. In dealing with the use of gas in an ordinary Lancashire boiler the author refers to the use of hot fireclay radiators, but he does not give any experience in connection with them. I hope that he will give this, because from experiments made with an ordinary gas stove it is known that 75 per cent of the thermal energy contained in the gas can be abstracted as radiant energy from the radiators, and that somewhere about 20 per cent goes away in the flue gas. If the same result can be achieved under a steam boiler, one gets about the same proportion of radiant energy to heat in the flue gas as is the case when the boiler is coal-fired. It would seem, therefore, that such an arrangement might be adapted easily to an ordinary Lancashire boiler. But there is a form of radiant energy which is not touched upon in the paper. Why is it impossible to use a flame, not of the Bunsen type, but of the radiant type, arranged in the ordinary boiler tube so as to get the energy in the form needed without the use of this radiating fireclay? If such a thing is possible it would be well to know why it is not used. The question of the use of high-velocity flue gas is not really one of boiler efficiency at all; it is one of evaporation per square foot of surface and of capital cost. If the gas is passed at very great speed along the surface which we desire to heat we may get a very much greater evaporation from that surface, but the cost of doing that may be greater than the interest on the capital

Dr. Cramp.

* See British Association Report, 1915.

Mr. Crampton. involved in increasing the surface of the boilers to get the same result. In other words one can always replace rapidity in the conduction of heat by increased boiler surface. Perhaps the author can give some figures bearing upon this question. I would also ask him upon what he bases his statement that superheat only pays up to 85 degrees C. Why does it not do so at 86 degrees C.? Why should it not pay at a much greater temperature than even that? What is it that determines the limit? Again, why is it stated that excess air should be used up to 20 per cent? Where does this limit come from? Is it a matter of present practice or does it follow from some reasoning not evident in the paper? We have all had experience of losses due to bad boiler-setting, but I would lay stress upon the difference in such losses between forced draught and induced draught. With forced draught in front of the boiler, all the way along right up to the base (or it may even be the top) of the chimney the pressure is slightly above atmosphere; so that while some hot gas may leak out, the draught on the fire bed is not impaired. With an induced-draught fan there is in the boiler flues a pressure below atmosphere and at the chimney base a pressure above atmosphere. As a result any leakage both reduces the air drawn through the fire and also cools the hot gases. It is therefore more serious than leakage in flues under forced draught. With regard to the Le Chatelier formula quoted in the paper, there is some doubt as to whether it has ever been sufficiently proved. I should like to ask the author whether it has not been called in question by recent research. The author says that the Pitot tube is difficult to work with. He mentions in the same breath the anemometer, an instrument which is not to be mentioned in the same hemisphere as the Pitot tube. It is a comparatively easy matter to design a Pitot tube which can be arranged to give good results with a properly constructed manometer. For those who are interested in the matter I have brought here an instrument made by Mr. Frith which shows what can be done in the way of a portable apparatus for measuring gas accurately. Under ordinary circumstances this form of Pitot tube (or a Brabbée tube) * is more likely to give reliable results than the method upon which the author relies, namely, deduction of volumes from chemical analyses. In gas-firing it is at least as important to measure the air as it is to measure the gas, for it is the mixture that matters. Mr. Frith some time ago designed and put into operation in Sheffield, in connection with a gas furnace, an apparatus for measuring both gas and air which has enabled combustion to be carried on in a perfectly regular manner, leading to much more satisfactory results with the furnace than were possible before. In conclusion may I refer to a blemish in this paper which must strike any one who reads it from the scientific point of view. I refer to the extraordinary mixture of units. Kilograms change to pounds, degrees Centigrade to degrees Fahrenheit, and cubic feet to cubic metres in various parts of the paper without any apparent reason. It is to be hoped that this will be corrected by the author before the paper is published in the *Journal*.

* *Proceedings of the Manchester Literary and Philosophical Society*, 20 May, 1914.

Mr. E. V. Winstanley: The paper has been written with a view to being of service to anybody engaged in working out problems in connection with gas-fired boilers, and from that standpoint there are a number of points to which attention should be drawn. On page 58 a list of calorific values of the gases is given, and preceding it a statement to the effect that in this country we quote the number of therms in one cubic foot of gas at 60° F. and 30 in. pressure, and that on the Continent standard conditions are 0° C. and 760 mm. pressure. One would be justified in thinking that the figures given in the table are on that basis. It is not so, however, as the calories are certainly given for 0° C. and 760 mm. pressure, but the therms are given for 32° F. and 30 in. pressure. This is an important matter, as anybody using the table in the English units would be about 6 per cent out in his estimation of the calorific

Mr. Winstanley.

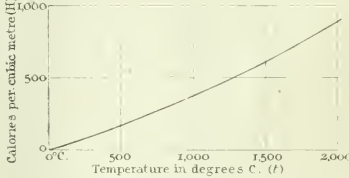


FIG. A.—Curve of temperature and total heat above 0° C. for one cubic metre of average flue gases.

value. On page 61 the author, as an example, gives calculations for the flame temperature and also the heat lost in the flues with a boiler using blast-furnace gas. There are one or two mistakes which make a slight alteration in the calculated temperatures, reducing the drop in temperature due to moisture to 230° C. as against 281° C. quoted by the author. There is a big mistake with regard to the loss in efficiency due to the pressure of water vapour. The author's figure of 204 calories lost to the flues with the dry gas is incorrect and should be 141 calories; also the figure of 207 calories should be 195. If the calculations are corrected throughout these figures become 140 and 179 calories respectively. This means that the loss to the flues is 14·5 per cent and 18 per cent respectively for the dry and moist gases, against the author's figures of 21 and 29·8 per cent. With this correction there is only a difference of 4·5 per cent in the output from a given quantity of gas, and not 12 per cent as stated. Finally, the results arrived at on page 62 are considerably altered, the drop in efficiency being nearer to 5 per cent than to 9 per cent as stated, and the drop in evaporation only 13 per cent and not 21 per cent. There is a convenient method of ascertaining the temperature of combustion that would save a lot of laborious calculation. It is found that the flue gases have a fairly constant heat capacity and I have drawn a curve of total heat and

temperature for one cubic metre of the average composition. This curve is shown in Fig. A. It is similar to the energy curve used in connection with gas-engine problems. The flame temperature of the gases obtained from the curve would be sufficiently near for the practical man, and from items taken from the author's tables at random I find it gives results within 3 per cent of the calculated temperatures, and the agreement is still closer for actual running conditions, i.e. about 25 per cent excess air. It would apply to all the gaseous fuels. The method of using the curve is as follows:—

Take producer gas (Table 15) with 33 per cent excess air.

Total volume of wet waste products = 2·464 cub. metre.
Calorific value of 1 cub. metre of gas = 1,431 calories.
∴ Heat added to 1 cub. metre of products of combustion

$$= \frac{1,431}{2·464} = 580 \text{ calories.}$$

Flame temperature from curve = 1,430° C.
Calculated flame temperature = 1,400° C.

This is sufficiently near for most purposes. The author has also described a Lancashire boiler in which the fine is led into a tube plate as being better suited for gas-firing than the straight-flued Lancashire boiler. That appears to me to be very like the ordinary Scotch marine boiler. Is the author aware of any boilers of this type being gas fired? Marine boilers are now in favour for land service, and it would be interesting to know if they would be of greater serivce than the ordinary Lancashire boiler for gas-firing. It is a pity the author does not give some actual figures of tests that he has taken, as, after all, such figures give the best information to people who wish to install gas-fired boilers.

Mr. S. L. Pearce.

Mr. S. L. PEARCE: I think this paper has a twofold aspect. From the national point of view there can be little doubt that to burn raw coal is quite unsatisfactory, but from the central station engineer's point of view it has been by no means demonstrated up to the present time that by the adoption of gas-firing the engineer will be able to produce a unit of energy at a lower cost than at present. I therefore think this problem may be brought nearer to a solution by the experimental station which will be established shortly at East Greenwich. I simply want to emphasize here that the two aims are by no means identical and that, whilst we may be doing the right thing from the national point of view by the adoption of gas-firing, it does not follow that it will enable the central station engineer to provide cheaper energy. He has not been able to any great extent in the past to take advantage of by-product gas, whether obtained from coke ovens or from blast furnaces; therefore we are thrown back upon two alternatives, either to put down producer plant in its entirety or else to purchase our gas. One notices at the top of page 58 that the author himself does not appear to be over sanguine in regard to the former, because he "thinks that in no case yet has the gas-firing of boilers with by-product producer gas been made a commercial success, as it has been found that steam could be raised more cheaply from the coal direct, even after allowing for all the income from the sale of by-products." Then he goes on to qualify that statement as if he thought he had said rather too much. He says he believes there are modern plants which can make the gas-firing proposition a commercial success under "suitable conditions." If he would be good enough to give more definite data on that point I should be very much obliged to him. With regard to the possible utilization of town's gas, I have made a calculation from the figures which are supplied by the author on page 59. I assume that no electrical authority, purchasing town's gas of which the calorific value was about 500 therms, could afford to pay more than about 2½d. per 1,000 cub. feet. Does the author think it at all likely that gas authorities will be in a position to offer gas at that price to the electrical authority? If they cannot, I see very little chance of that co-operation which has been advocated in certain quarters. With regard to producers, I do not want to say much, because I hope that before very long and in a place not many miles from here it may be possible to install experimental plant working in conjunction with modern marine boilers. As to the suitability of gas for boiler-firing, I am not at all impressed by the figures the author gives on page 60 in which he talks of it being possible with suitable combustion arrangements to obtain an evaporation of 5½ lb. per square foot. At one of our stations we are putting down boilers of a marine type from which we fully anticipate getting an evaporation of 7½ lb. per square foot. On reading the paper I felt some qualms as to the accuracy of taking the gas measurement, but I am glad to say they have been very much allayed by the remarks of Dr. Cramp. The author has such a real knowledge of this subject that he might very much enhance the value of the paper if he gave us the working results of at least one well-known installation utilizing coke-oven gas in conjunction with water-tube marine-type boilers.

Mr. Pear

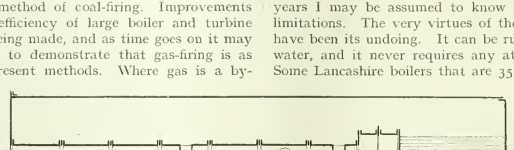
Mr. S. J. Watson.

Mr. S. J. WATSON: The author deals with the use of gas for firing boilers, which at once raises the question whether that is the most efficient method of using the gas. Most of us are aware that on the Continent the by-product waste gases, as they have been frequently termed, which come from coke ovens or from blast furnaces are used direct in large gas engines, and from the point of view of thermal efficiency there is no doubt that better results are obtained in this way than by burning the gas under any form of boiler. By making use of the blast-furnace gas which was previously wasted, some of the large ironworks have been able to reduce the cost of manufacturing iron by something like 4s. or 5s. a ton. The gas engines are mostly of large size, and consequently exceedingly efficient thermal results are obtained. I imagine that the question of gas-firing in boilers is very largely one of securing a steady flow of gas. Some time ago I saw on the North-East coast a large installation where gas is obtained from a neighbouring blast furnace. The amount of gas supplied fluctuated within tremendous limits. At some times there was none; at other times there was sufficient to fire several boilers. They have therefore to keep a number of boilers coal-fired in order to secure a steady production of steam. That is one of the diffi-

Mr. Wats

tson. culties which one is up against in making arrangements for the burning of gas. Then again the value of the gas from those two sources is very different. Whereas the thermal value of coke-oven gas is about 500 therms per cubic foot, blast-furnace gas varies from 100 or 150 down to a very low figure, which of course adds considerably to the difficulty of obtaining satisfactory results. The author refers to the considerable use of Lancashire boilers in connection with gas-burning. We all know that the Lancashire boiler by itself is incomplete without an economizer. If, therefore, a fuel is used which contains such a high percentage of moisture as he indicates, I should like to know what type of economizer they install. The efficiency of a Lancashire boiler will be very low without an economizer, and with considerable moisture in the flue gas the rate of deterioration of the usual type of economizer tubes must be exceedingly high. On the whole the paper may be taken as one of very great usefulness to us, but I am inclined to agree with Mr. Pearce that there is little likelihood that gas-producing plants for the firing of boilers are going to be substituted generally for the present method of coal-firing. Improvements in the thermal efficiency of large boiler and turbine plants are still being made, and as time goes on it may be more difficult to demonstrate that gas-firing is as economical as present methods. Where gas is a by-product instead of one of the principal products the position is quite different. There is one other point I should like to raise. That is with regard to the transmission of gas over appreciable distances. During the last few years quite a little controversy has been going on in the Press with regard to the manufacture and transmission of gas under pressure from collieries into the larger industrial areas. Some of us who have Mr. Watson. seen the *Strand Magazine* for December will have noticed the article by Sir Oliver Lodge where he shows the difference between the transport of coal and gas from the collieries. It seems to me we cannot effect the distribution of gas over large areas without suffering a somewhat severe loss, and it would be very useful if Mr. Hunter would give us a few figures to indicate the loss which may occur under such conditions. In one portion of the paper he mentioned that the cost of producing one ton of steam is about 1s. 3d. from coke-oven gas. Coke ovens are invariably established at or near collieries, and the cost of 1s. 3d. approximately corresponds to coal at 10s. a ton. I do not imagine that the class of coal which would be used for generating steam at a colliery will have a value of 10s. in normal times; it would probably be more like 4s., or perhaps in some cases even less; so that the comparison in this particular instance is not a very happy one.

Mr. D. Adamson: The author mentions water-tube Mr. boilers and Lancashire boilers, and as I have been Adamson. connected with the manufacture of both types for many years I may be assumed to know something of their limitations. The very virtues of the Lancashire boiler have been its undoing. It can be run with any sort of water, and it never requires any attention or repairs. Some Lancashire boilers that are 35 years old are now being reseated, having outlasted their foundations; others, 20 years old, have been recently sold second-hand for as much as was paid for them when new. The water-tube boiler may be regarded as the delicate child of the family. It has been spoiled and pampered by its parents, and doctored by professional attendants who then take credit for keeping the poor child going



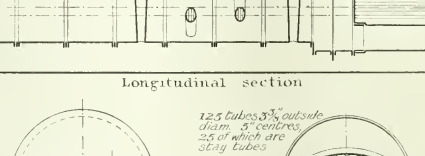


FIG. B.—30 ft. × 8 ft. multitubular Lancashire boiler.

Heating Surface.

Flues, cross-tubes, and combustion chamber				= 462 sq. ft.
Tubes	..	..	..	= 704 sq. ft.
Two-thirds of shell	..	..	..	= 500 sq. ft.
				1,666 sq. ft.

nson.

at all, and that has gone on so long that its users accept its limitations as a matter of course. The Lancashire boiler is everybody's and therefore nobody's child. Both types, however, have been brought up on very different fare from that now offered by the author. Clean water and clean fuel are very different conditions from what the Lancashire boiler has had and what even the water-tube boiler can get to-day. The water-tube boiler has emphasized the necessity for clean water, and the large gas engine the necessity for clean gas, and given clean water and clean fuel the possibilities are almost beyond our dreams in the way of improvement in boiler design. One such improvement would be the adoption of the Lancashire multi-tubular boiler mentioned by the author during the reading of the paper, and he will no doubt be interested in the accompanying diagram (Fig. B) of such a boiler, from which four were made 30 years ago. Although the purchaser would have been satisfied if they lasted seven years, they are still at work giving good results. The feature of the design is, as described by the author, an enclosed combustion space which avoids losses by air leakage or radiation, combined with a reasonable amount of heating surface suitably arranged for cleaning. The smaller tubes can be swept through while the boiler is at work, and they are made with ferrules so that they can be removed for scaling and replaced without damage. The large lower tube is for clearing the combustion chamber of flue dust without stopping the boiler. The author refers on page 65 to sufficient combustion space being an essential point in a water-tube boiler. It seems to me that this entails considerable wear and tear of brickwork and loss by radiation, although the figures given in the paper do not substantiate that. The author gives very much lower figures for radiation losses from the water-tube boiler than from the internally-fired boiler, which is not what would be expected. Another point is whether the covering of the brickwork with tar has been found to be satisfactory in general use, because, if so, it seems to be a valuable hint to all users of boilers. On page 63 the author mentions several methods of increasing the output of the boiler, but I venture to suggest that most of them are illusory when compared with the fourth method, especially if clean fuel and water are available. After describing it he refers to Dr. Nicolson's experiments. I have gathered in conversation that he is not in possession of the complete figures of Dr. Nicolson's experiment and I shall be glad to pass those on to him. On page 63 he says the gases were reduced from 1,260° C. to 425° C. in passage through the flue. That is not quite correct. There was a brick plug in the flue, but the reduction of the temperature in passing that brick plug was from about the figure given, 1,260° C., to about 700° C., and the 425° C. was the temperature after the gases has passed through what was called the evaporator, which was the next element in the arrangement. When the gases had gone through the economizer, which was the third step, the temperatures were brought down to 135° C. The author states that sufficient heat was transmitted to evaporate 36 lb. of water per square foot of the flue tube per hour. The original report of Mr. Michael Longridge states "that 40,000 B.Th.U.'s per square foot per hour were transmitted in this case," which means 40 or rather over 40 lb. of steam evaporated per square foot per hour. I should like to quote an extract from Mr. Longridge's report, referring to Dr. Nicolson's system: "The essence of the system is the saving of heating surface by using high gas velocities. If it can be embodied in an apparatus fairly durable, accessible and free from risk of inopportune obstruction of gas and water passages, I think it will prove to be of practical value in warships and other places where saving of space and weight are predominant considerations." My own personal view of Dr. Nicolson's experiments was that they put boiler design on a scientific basis for the first time. On page 65 of the paper the author refers to the advantages of high velocity for gases. I do not want Dr. Nicolson's work in this direction to be overlooked and I would refer members to his paper read in December 1910 before the Institution of Engineers and Shipbuilders in Scotland.

Mr. Adamson.

Alderman W. WALKER: I am sorry the author has not given us some examples of the practical application of gas-firing. We should have valued any information as to the means of leading in the gas, the position of the burners, method of fixing them, and their design, together with the system (if any) of distributing the gas, so as to avoid flame concentration on small areas of the front tubes. The question has occurred to me whether there would be any increase of efficiency if the temperature of the primary air were raised, and if so, whether it would not be possible in a central power station to make use for that purpose of the heated air from the alternators; the deciding factor would be cost of piping as against increase of efficiency. Another important point is the ratio of the space required for the producers to the space required for the boilers which they are serving. In many cases it would be decisive as to whether or not gas-firing is to be installed. As the space required for the producers for very large boilers going up to 100,000 lb. evaporative capacity per hour is greatly in excess of that required for the boilers themselves, it will alter the plans of the lay-out of the station and necessitate the covering of much more land. We shall not all agree with Mr. Watson that if we are going to use gas at all it ought to be used in internal combustion engines. He asked us to take it for granted that the overall thermal efficiency of the internal combustion engine is, and must be, higher than that of boiler plus turbine. The figures we have got from the tests of the large American sets and from some of those in this country show that the efficiency of the internal combustion engine has been equalled. The high initial cost of gas engines, together with the troubles in running them and other incidentals thereto, must convince us that the future is with large steam turbo-alternator sets, and we are back to the question of to-night's paper, viz. the method of boiler-firing. In a central power station, the place where increased efficiency is to be obtained is the boiler house. The series of papers which have been read on steam-raising agree that from 80 to 85 per cent efficiency ought to be obtained. If this can be done by producer gas or town's gas, then the question of by-products will assume extreme importance, though I do not think

Alderman Walker.

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that any central power station engineer will wish to be saddled with works and plant which will turn him into a manufacturing chemist. Power stations have been created and exist for the production of electricity, and the results of failure to supply are so disastrous that nothing that increases the risk is justified; therefore, before so radical a change as that advocated in the paper is adopted, experimental work on fairly large boilers ought to be undertaken. I wish that the solution could be for us to take gas from those who have expert knowledge of its production and know best how to utilize the by-products. The central station engineer has sufficient worries in his work at present without having to take up the study and control of gas production and by-product utilization.

Pearce.

Mr. J. G. PEARCE: With reference to Dr. Cramp's query regarding the Le Chatelier formulæ for the specific heats of gases at high temperatures, and to the whole theoretical basis of the author's calculations, it should be noted that these formulæ resulted from investigations carried out by Mallard

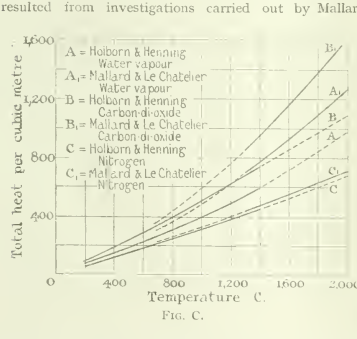

FIG. C.

and Le Chatelier published in 1887. The method adopted involved the combustion of the gas at constant volume, and the range of temperature over which the specific heats were measured was 1,300° C to 3,000° C. In 1905–7 Holborn and Henning published* results of experiments in which the gas was heated from an external source and maintained at constant pressure. The figures are in some cases the means of as many as 30 experiments, none of them varying more than 2 to 3 per cent from these means. The range of temperature went up to 1,400° C. The Committee of the British Association on Gaseous Explosions, the statements of which must be regarded as authoritative, reporting in 1908, considered that the values obtained by the explosion (Le Chatelier) method are affected by errors of quite unknown amount, due to heat radiated and to lack of thermal equilibrium when the pressure is at its maximum. At the same time it is probable that the values obtained by Holborn and Henning are too low. The differences are exhibited by the curves shown in Fig. C. The ranges over which the measurements were made are given by the full lines, while for temperatures outside the ranges, in which there is considerable danger in extrapolation, the lines are dotted. In accounting for the much higher values obtained by Mallard and Le Chatelier the influence of dissociation of steam and carbon dioxide at the high temperatures obtained cannot be fixed until further quantitative information is available regarding the equilibria of these systems at such temperatures. It is known that carbon dioxide is dissociated to some extent at 1,300 C to carbon monoxide and oxygen, while steam is considerably decomposed at 2,000 to 3,000° C. Both actions being endothermic, dissociation must be one of the causes of the higher figures, but the extent to which it operates is not known. While no method yet used gives accurate values of specific heats of gases at all temperatures, consideration of the most suitable formulæ to use in a paper like the present is important, owing to the rapidity with which tables such as those given by the author are reprinted, frequently without acknowledgment of their source. Whether accurate or not, the Le Chatelier results are more appropriate to gas-engine work, as at least arising from a method approximating to conditions obtaining in a gas-engine cylinder, while for problems in gas-firing boilers the constant pressure results of Holborn and Henning are to be preferred. In any case the latter results are recognized to be the most complete yet recorded, and yield formulæ for the mean specific heat at constant pressure between the range 0° C to t° C. for one cubic metre of gas at normal temperature and pressure as follows:—

Mr. Pearce.

Nitrogen

$$C_p = 0{\cdot}2948 + 0{\cdot}00002383\ t$$

Carbon dioxide

$$C_p = 0{\cdot}3962 + 0{\cdot}0001462\ t - 0{\cdot}00000003545\ t^2$$

Water vapour

$$C_p = 0{\cdot}3763 - 0{\cdot}00001354\ t + 0{\cdot}00000003546\ t^2$$

Mr. W. E. BERRY: The author has said very little in his paper about the Bonecourt gas-fired boiler and perhaps some information as to what is being done would not be amiss. I dare say members are mostly aware that the Bonecourt boiler was designed and first brought into use in this neighbourhood and the results were so astonishing that a very large experimental boiler was put in at the Skinningrove Iron Works. It was fired with gases from coke ovens. The efficiency on several tests was maintained at over 92 per cent, unlagged 2½ per cent was deducted for the fan so that the net efficiency was 90 per cent. No other boiler yet designed comes near that in heat efficiency. It was so satisfactory that the Skinningrove Company ordered a second boiler. They were so designed that they would evaporate 5,000 lb. per hour, and were of 10 ft. diameter, 4 ft. long between the tube plates, and fitted with 110 tubes each 3 in. in diameter. Every tube had a short plug through which a narrow pipe about ¾ in. diameter was led. These 3-in. tubes were packed with refractory material. The gas was allowed to flow in and lighted, ignition took place, and the refractory material got heated up for a short length.

Mr. Berry.

* *Annalen der Physik*, 1907, vol. 23. p. 809.

tory. The gas was turned off, and then on again, and flameless combustion took place, with the result that the whole of the refractory material inside the tubes became an incandescent mass, and we could easily get an evaporation of 20 lb. per square foot of tube surface. Of course we required a fan to draw gas through this refractory material and it was found on test that the fan required about 17 in. water-gauge to give satisfactory results and prevent the gas lighting back. A group of boilers was put in at the Birmingham Battery Company's works which evaporated 11,000 lb. an hour each, and the efficiency was just about the same. At the present time we are designing boilers capable of carrying 450 lb. pressure, so I think it will be agreed that the system is satisfactory. The only thing against it is the innate conservatism of engineers who do not like anything new until some one else has done the experimental work; then they are willing to benefit by his experience. The Bonecourt boiler is the most scientifically designed boiler that I know of. We had the temperature graded, and can get down the temperature of the gases discharged at the back end of the boiler to just a few degrees above the steam temperature. The author touched upon blast furnaces and coke ovens, but he said nothing about the waste gases from regenerative furnaces. That is a system which has come from America and a large number of experiments have been made with most satisfactory results. A paper on the subject was read before the Iron and Steel Institute at New York in 1915, and the best results were obtained with a Babcock boiler in which the transfer of heat was at the rate of about 7 therms per square foot of heating surface per degree of difference in temperature between the inlet and the outlet gases. In a paper recently read by Mr. Wans before the Institution of Mechanical Engineers he mentioned that his firm had got out boilers that had given an evaporation of 2 lb. per b.h.p. per hour. I know of Bonecourt boilers that have given 3 lb. per b.h.p. with waste gases, and it clearly indicates that we have built on the right track with this absorption of heat. Moreover, the refractory material in the tubes forms an excellent silencer; one cannot hear the exhaust of the gas engine. The author in his reply at the meeting stated that they had installed boilers which brought down the temperature of the escaping gases below the temperature of the steam in the boilers. This is a physical impossibility; further, the gases at such a low temperature would be abstracting heat from the boilers, thereby turning evaporators into condensers.

llcock. Mr. H. ALLCOCK: After listening to the paper and the remarks of previous speakers in the discussion I am of the opinion that the matter may be summarized in the author's own words on page 58 of the paper, namely, that the firing of boilers with producer gas is not a commercially sound proposition. I derive from that conclusion a certain amount of personal satisfaction, as it confirms the decision reached by those with whom I was associated some 17 years ago when I was personally engaged in attempts to adapt steam boilers of the tubular type for firing by Mond producer gas. We abandoned those attempts because there seemed to be no advantage to be gained by continuing them, and it is a proof of the soundness of our judgment to hear an expert like the author now acknowledge that, even after so many years of development work, producer-gas firing cannot be recommended when considered solely on a cost basis. Mr. Allcock

Mr. T. M. HUNTER (*in reply*): Mr. Paton's suggestion is interesting—that a boilerman who sets his burners to get a certain colour of flame is in reality setting his flame to be as far as possible towards the red zone of the spectrum. It is found that the colour of the flame, for the best composition, varies with every gas and with different conditions of the same gas. Of course, the setting of the flame by eye is merely a rough method by which an experienced boilerman can reproduce the results wanted by the engineer in charge of the plant. Mr. Hunter

In reply to Mr. Wollaston, 20 per cent excess of air is suggested in the paper as the best we hope to attain in ordinary working, on account of the variations in the quality of the gas to be burned. From Table 15 it appears that 17 per cent CO_2 in the producer gas there dealt with, corresponds to $13\frac{1}{2}$ per cent excess of air, which is an excellent result. My experience in producer-gas firing is that from 16 to $16\frac{1}{2}$ per cent CO_2 is the maximum which can be safely maintained, and that it is necessary to test very carefully for unburned CO as soon as the CO_2 rises to 17 per cent.

Several speakers have asked for the results of actual tests. I did not care to put into the paper results of tests made by myself, as testing gas-fired boilers is a subject in which it is very easy to show questionable results. An independent test was published recently on an installation in which I was interested, and this may be quoted. Mr. W. M. Selvey made a test on the Stirling boilers of the Yorkshire Waste Heat Company's electrical generating station at Barugh. The boilers are fired with coke-oven gas by means of Terbeck gas-burners. The gas was metered. Conditions were those of ordinary working. The gas pressure was quite low—about $\frac{1}{2}$ in. (water-gauge), instead of 3 in. for which the burners were designed. There are two boilers, each of 30,000 lb. evaporation, fitted with superheaters, but with no economizers. The net calorific value of the gas was 399 therms per cubic foot; average steam pressure 175 lb. per sq. in.; average temperature 290° C.; average temperature of flue gas 238° C.; efficiency, minimum 80·2, maximum 83·4, average 82·5 per cent: duration of test 40 hours. In general, given a modern boiler, in good order, with setting in satisfactory condition, fitted with superheater and economizer, we should expect to maintain the efficiency at the following figures, with careful management:—for coke-oven gas 85 per cent, for producer gas and cleaned blast-furnace gas 80 per-cent, for uncleaned blast-furnace gas (water-tube boiler—no economizer) 67 per cent.

In reply to Mr. Allcock, the want of success of producer-gas schemes for boiler-firing has been caused by the large amount of steam required to run the plant. This steam has to be deducted from the steam that is raised by the gas, whether it is put into the producer as live steam, or is first used in the plant and then put into the producer at a low pressure. The Mond pro-

Mr. Hunter. ducer requires $2\frac{1}{2}$ lb. of steam per pound of coal gasified. There is at least one modern producer which can be run with no more steam from the boilers than is needed to work the pumps and blowers—less than $\frac{1}{2}$ lb. per pound of coal gasified—the rest of the steam necessary being generated in a water jacket, by cooling the gas before it leaves the producer. The 2 lb. of steam per pound of fuel thus saved means nearly 50 per cent greater steam output, from each pound of fuel, available for generating power. It is found that this makes all the difference between success and failure in many schemes.

In reply to Dr. Cramp, I have made a number of experiments upon a Lancashire boiler, in order to discover whether a brickwork arrangement could be devised which, while not seriously diminishing the chimney draught, would allow much of the heat to be transferred as radiant heat. Many arrangements were tried, but the conclusion was that it was not possible under these conditions to heat the brickwork to such a degree that the transmission of heat was measurably improved. The result was practically the same in the case of brick baffles built in the flues. Such baffles aid greatly when it is necessary to mix air and gas during combustion, but this seems to be their sole function when working at ordinary chimney draught, and this action is not required when firing the boiler with suitable burners. As regards the figure mentioned as the usual superheat for steam, 85° C. has for long been the temperature most commonly used. I am aware that much higher temperatures are being used in certain new plants (c.f. Report in *Engineering* of 13th July, 1917, by Mr. F. Samuelson, on tests made on a B.T.H. steam-turbine plant). It might be added that separate superheaters, gas-fired, may lead to a considerable advance in steam-turbine economy, by permitting the steam to be reheated after passing through the first element.

I wish to thank Mr. Winstanley for pointing out certain errors in the calculations in the paper (these have now been corrected). By permission of Mr. Winstanley I have used the interesting curve which he has drawn, showing the total heat and temperature for average products of combustion, to add to the tables in the Appendix a further column showing the flame temperature possible with the various gases when diluted with different quantities of air. Three-flued Scottish marine boilers were used for gas-firing about 30 years ago on the North-East coast in connection with an early form of non-recovery gas producer. Theoretically they should give excellent results gas-fired, but I have not come across any so fired.

In reply to Mr. S. L. Pearce, the question of the price which an electrical station engineer could afford to pay for gas arose lately in the case of a modern Lancashire power station. Babcock boilers are used with fuel costing 18s. per ton, and containing 11,000 therms per pound. Assuming that the boiler efficiency is 75 per cent, the engineer would pay exactly the same for his fuel if he bought coal gas of 500 therms per cubic ft. net value, at 5d. per 1,000 cubic ft., or coke-oven gas of 450 therms per cubic ft. at $4\frac{1}{8}$d. per 1,000 cubic ft., and burned them at 85 per cent efficiency; or if he bought by-product producer gas of 140 therms at 1·32d. per 1,000 cubic ft. and burned it at 80 per cent efficiency. These figures are double those assumed by Mr. Pearce. There is in addition the saving to be considered in labour and maintenance when gas-firing; and also, for new stations, the capital saved where elevators, bunkers, stokers, and ash-handling plant are not required. The gas for boiler-firing need not be purified from the last traces of tar and naphthalene, as must be done in the case of gas going into small pipes; indeed these would actually enrich the gas. In this way another small reduction could be made in the cost of the gas. Even if the gas department could not sell gas to the electricity department at 5d. per 1,000 cubic ft. during the whole of the year, it might do so in the summer months. It would be a fair proposition to charge nothing for capital charges on the gas taken by the electrical department in summer, as these charges are covered by the price of the gas sold to outside customers, and the new use for the gas would greatly assist in improving the load factor at the gas works.

Mr. Watson asks as to the type of economizer used for Lancashire boilers when gas-firing. The usual Green's type with cast iron tubes is used, and no trouble is experienced when reducing the temperature of the chimney gases to 200/230° C. When burning cleaned gas, a cheaper and more efficient form of economizer can be used. No scrapers are needed, as there is no deposit from the gas, so that the economizer can be completely closed in and free from air leakages. As to the loss of gas in transmission over long distances, I am informed that in America, where natural gas is piped great distances, $\frac{1}{2}$ per cent is the loss in favourable cases, and up to 2 per cent in other cases. The sum of 1s. 3d. was not given on page 59 as the cost of producing one ton of steam by coke-oven gas. This figure was merely assumed as the cost per ton of steam raised by coal-firing. Perhaps 1s. per ton would have been a safer figure to use, but I have found, on looking into the question at many collieries, that when a very low value is claimed for the boiler fuel, a very low evaporation is got out of it.

Alderman Walker raises the question of the distribution of the flame in the combustion chamber so as to avoid damage to the lower tubes. I try to arrange in every case that the gas burners fitted to water-tube boilers point downwards at some 20°, so that the gases shall not impinge on the tubes until they are thoroughly burned. The oxygen in the gases at this stage—usually about 3 per cent when running under the best conditions—is so small that the gases cannot hurt the tubes. It is a great advantage to burn gas with preheated air. The heat units in the air are added to the calorific value of the gas, thus giving a higher flame temperature. It does not seem probable that it would pay to install piping to connect the alternators to the burners for the sake of the small amount of heat produced when they are ventilated; but such ventilating air might usefully be delivered into the boiler house, and would raise slightly the temperature of the air there, which is being drawn into the boilers.

Hunter. Mr. Berry has questioned the accuracy of a statement that the waste gases escaping from a gas-fired boiler could be at a temperature less than the steam leaving the boiler. The statement of course refers to the case of most water-tube boilers, which have a superheater as an integral part of the boiler. The gases, in the case of the test made by Mr. Selvey given above, were at 238° C., while the average steam temperature was 290° C. With regard to the efficiency which Mr. Berry claims for the Bonecourt boiler, I understand that this efficiency is to a considerable degree due to the special form of economizer used. This economizer might equally well be used with boilers having the additional advantage that they can be coal-fired when required. The objection to this economizer is that, being made of steel, its life is very short owing to corrosion, the gases being reduced in temperature to below 100° C. Mr. Hunt

Mr. J. G. Pearce and others have pointed out the defects of the Le Chatelier formulæ used in the Appendix. I looked into this question before the paper was published, and I found that the differences at low temperatures were so small as to be negligible by engineers dealing with boiler flue-gases.

ELECTRICAL COOKING AS APPLIED TO LARGE KITCHENS.

By W. A. Gillott, Associate Member.

(*Paper first received* 25 *October*, 1916, *and in final form* 20 *December*, 1917; *and read before* The Institution, 6 *December*, *before the* Manchester Local Section, 11 *December*, *and before the* Yorkshire Local Section, 18 *December*, 1917.)

Owing to the favourable tariffs now in force in most districts, electrical cooking in large kitchens is now a sound commercial proposition. In new premises, where it is proposed to run the kitchens on up-to-date and efficient lines, electricity is usually employed. In choosing the title "Electrical Cooking as Applied to Large Kitchens," the author means the words "large kitchens" to apply more particularly to the class of kitchen met with in restaurants and in works or other large business premises when staff-feeding is required for a large number of employees. In Newcastle-upon-Tyne there are several such institutions depending entirely upon electricity for cooking. The author considers the future of this branch of electrical industry to depend, first, upon close co-operation between the supply company's engineer and the manufacturer, and secondly upon the interchange of ideas and experiences between different supply companies and municipal engineers who have the plant actually running on their own mains. This paper has therefore been prepared in the hope that the facts and illustrations given may be of use to others who are engaged upon or are considering similar work; also to show that electrical cooking is not only extensively used in large kitchens, but also found to be reliable, efficient, and economical. Records are given showing the results over many months of serious work and indicating the consumption of electrical energy and the cost of maintenance per 1,000 units consumed; charts showing the nature of the load on the system are also included. The figures given have been obtained under ordinary working conditions, and in some cases without the knowledge of the cook using the apparatus. They can therefore be taken as a basis for similar installations working under somewhat similar conditions.

In drawing up a scheme for cooking in large kitchens, the essential items are:

(1) Reliability;
(2) Quick Service;
(3) Efficiency.

Reliability.—Under this item the question of electrical distribution from the service cables is as important as the electrical work on the apparatus itself. This is more so at a restaurant where there are serveries on different floors, quite apart from the kitchen, than in an establishment where staff-feeding is only required with the kitchen adjacent to the dining rooms. In the latter case a cable from the service to the distributing centre in or near the kitchen is all that is required; but in the former case, especially where the total loading of the apparatus in the serveries is appreciable, two pairs of cables should be brought from the service, which on large installations should be the main distributing centre, to each servery and kitchen. This system, in the author's opinion, is better than balancing one servery or kitchen against the other, as in the event of a fault developing on the mains only a section of the apparatus will be put out of commission.

In each kitchen or servery these cables should terminate in a double-pole switch of ample size and single-pole fuses of the replaceable pattern, and connections be provided to supply through branch single-pole fuses to the various pieces of apparatus, each of which should be controlled by a double-pole switch adjacent to the same. It may be argued by some engineers that to place a piece of apparatus on a separate circuit with its own switch and fuses is an extravagance, but the author is strongly of the opinion that it leads to economy by securing reliability, inasmuch as if a fuse blows only one piece of apparatus is affected.

The apparatus itself must be of solid construction and designed to stand hard and continuous wear, and be efficiently earthed. All switches and fuses must be fixed on a separate board within easy reach of the chef, and each section of the apparatus should be fitted with a switch, fuse, and indicator. The internal wiring of the apparatus must be so fitted that it is practically impossible for steam to penetrate through to the insulation. On well-designed apparatus solid type connections are employed, and where a connection is required from, say, a hot-plate to the terminal chamber, the wiring may be run in solid-drawn tubes direct from the hot-plate case to the terminal box, this being fitted well up and away from any position likely to be affected by liquids boiling over. It will be seen that, by this method, flexible metallic tubing is dispensed with, thereby removing a weak link.

All elements except the grills should be connected in series-parallel, and where possible they should be so arranged that after the cooking has thoroughly commenced, they can be switched to "low" and provide sufficient heat to complete the operation. Under these conditions the elements are running at quarter load during the majority of the time, with the result that the elements have a much longer life than if parallel elements were employed throughout.

On apparatus where the heating elements are clamped under pressure, such as hot-plates, water boilers, stock pots, steamers, etc., the pressure plates should be made of strengthened cast iron in preference to wrought iron, in order to prevent them from buckling and causing uneven bearing surface on the element. The element should cover as much surface as possible, as concentration of heat on apparatus of this class is likely to cause premature failures. On apparatus where the loading is comparatively high, it is advisable to employ

cast iron or steel bottoms in place of copper. Instances have occurred in the author's experience where the adoption of cast-iron and steel bottoms on large boiling units has overcome the trouble of premature failures.

Quick service and efficiency.—These two items, so far as the chef is concerned, come under one heading and can therefore be dealt with together.

In laying out a cooking scheme for a large kitchen, it is essential to arrange the apparatus so that the chef can supervise the cooking with a minimum of effort. By a judicial classification of apparatus, such as grouping all roasting and oven work in one section, vegetable and pudding steaming, etc., in another, and toasting, egg-poaching and tea-making in another, it is possible considerably to increase the efficiency of the kitchen, inasmuch as quicker service is given and a possibly smaller kitchen staff required. In restaurant work, where special attention must be given to ensure quick service, it is often necessary to provide special apparatus to deal with some classes of food which are required at a moment's notice.

Where large quantities of water are required for tea-making, the author recommends that the water be raised to a temperature of approximately 160° F. by means of a coke boiler or live steam, the final boiling being carried out in self-contained electric urns, the sizes of the urns, of course, being suited to the demand. The author usually fixes urns in banks of two, each supplied with hot water through a hand-fed valve, and arranged so that as one is being emptied, the other is boiling up ready for use. By this method, one is always in a position to meet a " rush on teas." In some cafés, toast is often in great demand. By using suitable racks, several pieces of bread can be toasted at one time. At the installation under Item " A ," 2,000 pieces of toast can be supplied in one hour.

Plate and dish-warming is a very necessary item, especially in restaurants where ample accommodation is essential. This becomes very important on installations such as " A " below, where dining rooms are on several floors. Hot cupboards for this class of work should be lagged, as they are called upon to work several hours a day, and, by conserving the heat, running costs are kept down. The question of keeping food hot is also a very important item, and in restaurants this has to be carried out in an entirely different manner from that adopted in staff-feeding establishments, where the meals are usually provided at a specified time each day. Properly designed apparatus is therefore supplied to provide the correct heat and to keep the cooked food in perfect condition.

When specifying the essential items in large kitchen practice, it will be observed that efficiency was placed third. It is not suggested that electrical efficiency should be disregarded altogether, but the author is convinced that the " man who pays the bill " would prefer to pay a little more for energy, knowing that he was getting this returned in reliability. It would be a serious thing, for instance, if a restaurant or staff kitchen were half an hour late with a meal owing to a breakdown caused by endeavouring to extract the highest possible efficiency from a piece of apparatus at the expense of reliability.

Upon referring to the schedules of installations, it will be noticed that the number of hot-plates has been kept low, and several pieces of self-contained apparatus have been provided. This is more practical than cooking in utensils on hot-plates. This may be objected to owing to the increased initial cost, but it is money well spent, and the policy should be adopted wherever possible. Where hot-plates are used, the loading should not exceed 20 watts per square inch for an 8-in. plate.

The following schedules contain particulars of some of the installations equipped in Newcastle, and give sufficient evidence that satisfactory results are being achieved on this class of work.

In giving details of these installations, the author does not wish to convey the idea that every restaurant or staff-feeding establishment should be supplied with the same pieces as those specified. As is well known, every establishment has its own special condition, and each has to be dealt with accordingly: for instance, at installation " A," the menu is of a very varied nature, but at installations " B " and " C " the menu is only slightly varied to suit the different classes of persons catered for. If we take the case of a workhouse or an asylum, where large quantities of one class of food are required, larger pieces of apparatus would be installed, and owing to the less variety in the menu, a smaller number of pieces of apparatus would be supplied.

INSTALLATION " A " (SEE FIG. 1): CONNECTED SEPTEMBER 1916. CLASS—RESTAURANT.

Main Kitchen.

Item	*Description*	*Loading*
Baker's oven ..	One piece. Made up in heavy gauge cast iron. Sides, back and top lagged with 3 in. of slag wool. Two decks, measuring 38 in. × 40 in. × 8 in. and 14 in. respectively, heated by crown and sole elements, split into 12 sections and arranged for 3-heat control on each section by series-parallel switches. Interior of ovens lined with tiles.	15 kw.
Double oven range	Two ovens under one hob-plate, each oven measuring approximately 22 in. × 22 in. × 26 in., and arranged for 3-heat control. Hob-plate fitted with two 10-in. and two 8-in. boiling rings, each with 3-heat control. Ovens well lagged with slag wool, the whole outfit made up in heavy-gauge cast iron. All wiring carried outside of range, with provision for easy inspection and renewals.	17·5 kw.
Double oven range	Ditto.	17·5 kw.

Item	*Description*	*Loading*
Hot cupboard..	Made up in cast iron and mild steel. Sides lagged with asbestos. Cupboard measuring 6 ft. 6 in. × 2 ft. × 2 ft. 7 in., top plate of cupboard plain, heated separately from interior, each section arranged for 3-heat control. Sliding doors on one long side.	6 kw.
Hot cupboard..	Ditto, but fitted with sliding doors on both sides.	6 kw.
Fish range ..	Six oval fryers, each measuring 22½ in. × 15 in. and loaded to 3 kw. and arranged for 3-heat regulation. The fryers mounted on cast-iron table, with high back skirting with drip pans over each fryer. A canopy is fixed over the whole suite.	18 kw.
Continental-type steamers	One range of 4 pans each measuring 17 in. × 12 in. × 12 in., made up in mild steel and loaded to 3 kw. each, and arranged for 3-heat regulation, each containing one block tin steamer, all mounted on cast-iron stand and provided with drip gutter.	12 kw.
Grills and toasters	One combination grill and toaster fitted in tiers one above the other, bottom grill with fat drawer, centre toaster, top hot cupboard, each unit loaded to 4 kw. All made in cast iron with porcelain enamel interiors.	8 kw.
Grill and toaster	Ditto.	8 kw.
Egg poachers ..	One poacher with 6 inset to take 12 eggs. Case made in heavy copper, nickel plated. Loaded 2·2 kw. with 3-heat regulation.	2·2 kw.
Egg poachers ..	Ditto, but for 6 eggs and loaded to 1·5 kw.	1·5 kw.

Café Servery.

Hot cupboard..	One 5 ft. × 2 ft. 6 in. × 2 ft. cupboard fitted with sliding doors. Cupboard loaded to 3 kw. with 3-heat regulation Top fitted with four 8-in. hot-plates, each loaded to 1·1 kw. and arranged for 3-heat regulation.	7·4 kw.
Grill and toaster	One combination grill and toaster as in main kitchen.	8 kw.
Water urn ..	One 10-gallon urn in copper, nickel plated with flat lids (to accommodate cups, etc.) loaded to 6 kw. with 7-heat regulation, supplied complete with gauge glass and thermometer. Urns fed with water at 150° F. through hand-fed valve.	6 kw.
Water urn ..	Ditto.	6 kw.
Café-au-lait ..	One 3-jar suite, each jar of 5 pints capacity, fitted with water bath. Jars sunk in wells. Made in heavy copper, nickel plated, loaded to 3 kw. with 3-heat regulation.	3 kw.
Egg poacher ..	One for 12 eggs as in main kitchen.	2·2 kw.
Egg poacher ..	One for 6 eggs as in main kitchen.	1·5 kw

Smoke-room Servery.

Hot cupboard..	One special type measuring 7 ft. 3 in. × 2 ft. 6 in. × 2 ft., fitted complete with two Continental type steamers (as in main kitchen) two 8-in. hot-plates and warmed top. Cupboard loaded to 3 kw.; top to 1·5 kw.; steamers to 2 kw. each and hot-plates to 1·1 kw. each, all arranged for 3-heat regulation. Sides of cupboard lagged.	10·7 kw.
Hot cupboard..	One measuring 6 ft. × 2 ft. 6 in. × 2 ft. fitted with 3 carving wells and overhead gear, and one Bain Marie. Cupboard loaded to 3 kw. and heated separately from carving wells, which are loaded to 2 kw. and Bain Marie to 1·5 kw. all with 3-heat regulation. Sides of cupboard lagged.	6·5 kw.
Grill and toaster	One combination as in main kitchen.	8 kw.
Grill and toaster	Ditto.	8 kw.
Water urn ..	One 10-gallon, as in café servery.	6 kw.
Water urn ..	Ditto.	6 kw.
Café-au-lait ..	One as in café servery.	3 kw.
Warming cabinet	One cabinet in two tiers, arranged with top heat for keeping savouries hot. Each unit loaded to 1·5 kw. arranged for 3-heat regulation. Suite made up in cast iron, all nickel plated.	3 kw.
Fish fryer ..	One made up of cast iron, similar to main kitchen, but measuring 15½ in. × 8	

Item	*Description*	*Loading*
	in., loaded to 2 kw. with 3-heat regulation.	2 kw.
Fish fryer ..	Ditto.	2 kw.
Egg poacher ..	Poacher for 12 eggs.	2·2 kw.
Egg poacher. ..	Poacher for 6 eggs.	1·5 kw.

Dining-room Servery.

Hot cupboard..	One special type, as in smoke room.	10·7 kw.
Hot cupboard..	One 6 ft. with carving wells, as in smoke room.	6·5 kw.
Toaster ..	One toaster measuring 24 in. × 10 in. (toasting space) fitted with hot cupboard oven, outfit made in cast iron and nickel plated, with white porcelain interior. Heat unit split in half and arranged for 2-heat regulation.	4 kw.
Water urn ..	One as in smoke room.	6 kw.
Water urn ..	,, ,,	6 kw.
Café-au-lait ..	,, ,,	3 kw.
Egg poacher ..	Poacher for 12 eggs.	2·2 kw.
Egg poacher ..	Poacher for 6 eggs.	1·5 kw.
Warming cabinet	One as in smoke room.	3 kw.
	Total loading of whole equipment	247·6 kw.

INSTALLATION "B" (SEE FIG. 2): CONNECTED AUGUST 1915. CLASS—STAFF FEEDING.

Kitchen.

Item	*Description*	*Loading*
Roasting oven	One cabinet-type measuring internally 2 ft. 9 in. × 2 ft. 4 in. × 4 ft. 4 in., loaded to 15 kw. with 2 sets of elements on each side and back, arranged for 6-heat regulation. The outfit made up in heavy grade cast iron with sides well lagged with 2 in. of slag wool, large fat drawer fitted at bottom, shielded from heat by drip pan.	15 kw.
Oven range ..	One treble oven range with two ovens measuring 22 in. × 22 in. × 26 in., loaded to 5 kw. with 3-heat regulation, and one pastry oven of 2-deck type, loaded to 4 kw., each deck measuring 22 in. × 22 in. × 13 in. Range fitted with two 12-in., two 10-in., two 8-in. and one 6-in. hot-plates, all arranged for 3-heat regulation. Whole outfit made up in heavy gauge cast iron, and ovens well lagged with slag wool	24·9 kw.
Vegetable steamer	One double steaming oven in heavy gauge cast iron, each oven containing 5 galvanized iron trays, each capable of holding 28 lb. of potatoes (or equivalent in puddings, etc.), water-fed automatically by means of ball-valve cistern. Each oven loaded to 5 kw. and arranged for 3-heat regulation.	10 kw.
Water and coffee urns	Three 10-gallon water urns, in copper, each loaded to 5 kw. and arranged for 3-heat regulation. One 10-gallon coffee urn, in copper, with earthenware interior, loaded to 3 kw. The four urns fitted on galvanized cast-iron stand, fitted with rubber buffers and drip drain.	18 kw.
Stock pots and soup boiler	Four 10-gallon copper pans, each loaded to 3 kw. with 3-heat regulation, fitted on galvanized cast-iron stand as above.	12 kw.
Fish range ..	Four fish fryers, two measuring 22½ in. × 13 in. loaded to 3 kw. each, and two measuring 15 in. × 10 in., loaded to 2 kw. each, all arranged for 3-heat regulation. The fryer made up in cast iron, and fixed on planished table, measuring 4 ft. 10 in. × 2 ft. 6 in. × 2 ft. 10 in.	10 kw.
Grills	One suite made up of 2-tier grill, measuring 30 in. × 10 in., each loaded to 5 kw. and arranged for 2-heat regulation, i.e. in halves. Made up in cast iron and fixed on brackets to the wall.	10 kw.
Hot cupboard..	One cupboard, measuring 6 ft. × 2 ft. 6 in. × 2 ft. 8 in., top containing 3 carving wells. Cupboard loaded to 3·5 kw. and top to 2·5 kw. Each arranged for 3-heat regulation.	6 kw.
Water urn ..	One quick-boiling urn, in copper, of 1-gallon capacity, for kitchen staff purposes. 3-heat regulation.	2 kw.
Egg poacher ..	One poacher in heavy copper, with 3 insets, each with a capacity of 2 eggs, i.e. 6 in all.	1·5 kw.
Egg poacher. ..	Ditto.	1·5 kw.

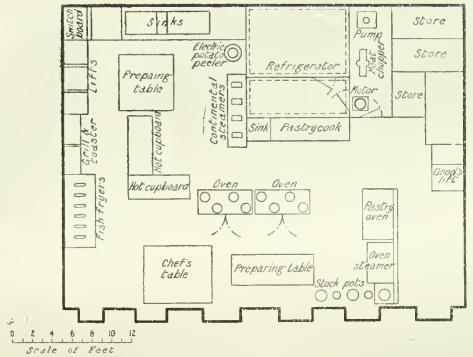

FIG. 1.—Plan of electrical apparatus in main kitchen at Installation "A."

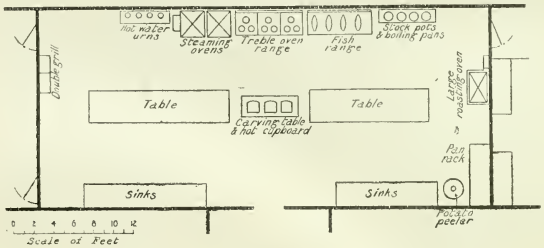

FIG. 2.—Plan of electrical apparatus in kitchen at Installation "B."

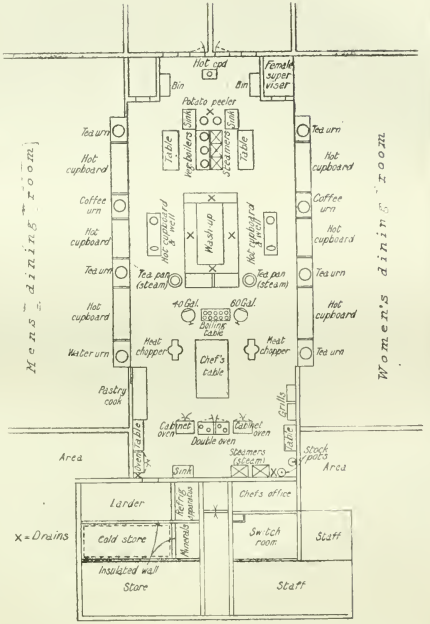

FIG. 3.—Plan of canteen kitchen cooking arrangements and lay-out designed by the author.

Item	*Description*	*Load*
Servery 1.		
Hot cupboard..	One cupboard measuring 3 ft. × 2 ft. 3 in. × 2 ft. 9 in. fitted with 2 carving wells, cupboard loaded to 2·5 kw. and top to 1·5 kw., each arranged for 3-heat regulation. Outfit made up in cast iron.	4 kw.
Servery 2.		
Hot cupboard..	Ditto.	4 kw.
Servery 3.		
Hot cupboard..	One cupboard, measuring 5 ft. × 2 ft. 3 in. × 2 ft. 9 in. fitted with 3 carving wells and 2 sauce pots, cupboard loaded to 3·5 kw. and top to 2·5 kw. Each arranged for 3-heat regulation, and outfit made up in cast iron.	6 kw.
Servery 4.		
Hot cupboard..	Ditto.	6 kw.
	Total loading of kitchen equipment	130·9 kw.

The following are installed in the same building, but in no way run in conjunction with the larger kitchen :—

Double oven ..	One double oven range, each oven measuring 18 in. × 18 in. × 14 in., loaded to 3 kw. each. Over ovens is fitted hobplate containing three 8-in. and one 6-in. hot-plate, and one grill 18 in. × 10 in., all (except grill) arranged for 3-heat regulation.	13·2 kw.
Water urn ..	One 4-gallon urn, in copper, loaded to 3 kw., arranged for 3-heat regulation.	3 kw.
Special warming suite	One special suite, made up of hot cupboard measuring 6 ft. × 2 ft. 6 in. × 2 ft. 9 in. with one 15-gallon urn, one grill measuring 24 in. × 10 in. and two 8-in. hot-plates fitted on top, cupboard loaded to 4 kw. Urn loaded to 8 kw. Grill to 4 kw., and hot-plates to 1·1 kw. each. All (except grill) arranged for 3-heat regulation. The whole suite made up in cast iron, except urn, which is in copper.	18·2 kw.
	Total loading of large and small kitchen equipments	165·3 kw.

INSTALLATION "C": CONNECTED JUNE 1914. CLASS—STAFF FEEDING.

Item	*Description*	*Loading*
Double oven ..	One double oven range, each oven measuring 24 in. × 22 in. × 26 in., loaded to 5·5 kw. Over the ovens on a hobplate are fitted one 12-in., one 10-in., and four 8-in. hot-plates and a grill 18 in. × 10 in. All (except grill) arranged for 3-heat regulation.	23 kw.
Vegetable boiler	One 4-gallon copper boiling pan, complete with three block tin steamers. Pan loaded to 3 kw. and arranged for 3-heat regulation.	3 kw.
Water urn ..	One 4-gallon copper water urn. Loaded to 3 kw. Arranged for 3-heat regulation.	3 kw.
Grill	One 24 in. × 12 in. grill, loaded to 4 kw. Arranged for 2-heat regulation (in halves).	4 kw.
Hot cupboard..	One 3-ft. hot cupboard, made in mild steel with lagged sides. Cupboard loaded to 2 kw. Top with 2 carving wells, and loaded to 1·5 kw. Both arranged for 3-heat regulation.	3·5 kw.
Carving table ..	One 5 ft. 6 in. carving table, fitted with 2 carving wells and 2 vegetable pots, each capable of holding 28 lb. of vegetables. Pots standing in a water bath, which is loaded to 2 kw. The carving top loaded to 2 kw. Arranged for separate control and 3-heat regulation.	4 kw.
	Total loading of whole outfit	40·5 kw.

INSTALLATION "D": CONNECTED MARCH 1915. CLASS—STAFF FEEDING.

Item	*Description*	*Loading*
Double oven ..	One double oven range with ovens measuring 18 in. × 18 in. × 14 in., each loaded to 3 kw. with hobplate over, containing two 10-in., three 8-in. and one 6-in. hot-plates. All arranged for 3-heat regulation. The outfit is made up of heavy gauge cast iron and ovens well lagged with slag wool.	13·3 kw.

Item	Description	Loading
Boiler ..	.. One 12-gallon heavy gauge copper boiling pan for vegetables, etc., complete with two block tin steamers, loaded to 6 kw. with 7 regulations of heat.	6 kw.
Steamer	.. One cabinet type pudding steamer, measuring 12 in. × 12 in. × 12 in. inside, made up in cast iron, and supplied with an automatic supply of water through ball-valve cistern. Outfit loaded to 2 kw. and arranged for 3-heat regulation.	2 kw.
Grill ..	.. One grill measuring 24 in. × 10 in., loaded to 4 kw. with 3-heat regulation. Made up in cast iron and stands on four 6-in. legs.	4 kw.
Fish fryers	.. One oval fish fryer, measuring 15 in. × 10 in. loaded to 2 kw. with 3-heat regulation. Made up in cast iron.	2 kw.
Water urn	.. One 4-gallon urn, in copper, loaded to 3 kw. with 3-heat regulation.	3 kw.
Hot cupboard..	One cupboard measuring 3 ft. × 2 ft. 9 in. × 1 ft. 10 in. loaded to 2·5 kw. with 3-heat regulation, outfit made up in cast iron with mild steel sliding doors.	2·5 kw.
	Total loading of whole equipment	32·8 kw.

The following table shows the details of consumption, cost of maintenance, etc., on the installations referred to.

In conjunction with these figures, one must also consider the advantages of electrical cooking from the economy of labour and food, simplicity of operation, the less fire risk, the saving on utensils, cleanliness, and the less floor space required as compared with coal, gas, or steam.

The details of operation of the supplementary plant at installation "B" are not included in this analysis, or in the chart showing the nature of the load, as in both cases they are used mostly for warming up food; if included, the figures would complicate matters when making comparisons.

In the analysis, all elements, etc., that have been supplied free under guarantee have been included at their ordinary costs, workmen's train fares have been

Installation	Period of Observation	Consumption in Units	Average number of Meals per Week				Cost of Maintenance per 1,000 Units consumed	Kw connected	Remarks
			Breakfasts	Lunches	Teas	Total			
"A"	10 months	122,052	389	5,186	3,943	9,518	1s. 6½d.	247·6	See below
"B"	1 year	97,140	204	1,480	1,260	2,944	2s. 9d.	130·9	
"C"	1 year	21,141	211	452	328	991	3s. 9½d.	40·5	
"D"	1 year	20,690	48	371	221	640	4s. 6½d.	32·8	

Remarks.—"A." In addition to the figures of meals, there is a weekly average of 600 Bovrils and hot drinks. The list of the quantity of food cooked is a weekly average. From tests taken, the consumption of energy per person served, including staff, is 0·29 unit per meal. Maintenance costs are for the first year's working.

"B." The list of the quantity of food cooked and consumed on an average day gives a good indication of the nature of the work performed. There are, however, several items carried out by the apparatus which do not come under the heading of cooking for the staff. The estimated consumption of electricity per person is 0·5 unit per meal. Maintenance costs are for the second year's working.

"C." No list of food cooked has been obtained from this installation, but the consumption of electricity per person per meal is found by taking various tests to be 0·41 unit. Maintenance costs are for the third year's working.

"D." In addition to the number of meals provided, there is a weekly average of 106 Bovrils and hot milks, and 50 lb. of bread baked and 9 suppers. There are also occasions when large quantities of food are cooked and consumed at other places, a list of which is given. From various tests carried out, the consumption of electricity per person catered for is 0·51 unit. The cost of maintenance on this installation is high in comparison with the others; this, however, is due to the fact that during the last 18 months the apparatus has been catering for an increase of 100 per cent more people than originally intended. Maintenance costs are for the second year's working.

omitted in order to make a true comparison with those installations close to the workshop.

MAINTENANCE ANALYSIS OF INSTALLATIONS "A," "B," "C," AND "D."

Installation	Elements							Wiring Faults	Earthing Faults, Terminals, etc.
	Oven	Hot-plate	Grill	Urn	Hot Cupboard	Fish Fryer	Vegetable Steamer		
"A"	4	2	7	—	—	—	—	17	4
"B"	20	16	25	5	2	3	7	27	25
"C"	—	22	1	1	—	—	—	14	3
"D"	2	28	28	—	—	—	—	17	2

Average quantity of food cooked and consumed at installation "A" *per week* :—

1,362 lb. of roast meat.
140 birds (average weight 3 lb. each).
282 grills.
300 lb. of sausages.
35 gals. of soup.
2,162 portions of fish.
140 lb. of Yorkshire pudding.
2,940 lb. of potatoes.
10½ pecks of peas.
63 cabbages.
84 lb. of turnips.
56 lb. of carrots.
56 lb. of milk pudding (in dry state).
854 portions of ham and eggs on toast.
1,150 cups of coffee.
915 gals. of water boiled from 150° F.
1,265 portions of hot sweets.
112 lb. of scones.
42 lb. of pastry.

Average quantity of food cooked and consumed at installation "B" *per day* :—

79¾ lb. of roast beef.
34 lb. of haricot mutton.
10 gals. of potato soup.
21 lb. of peas boiled.
10 lb. of beans boiled.
112 lb. of potatoes.
½ gal. of vegetable stock.
6 gals. milk pudding.
1 gal. of hot milk.
2 hams boiled (28 lb.).
80 eggs fried and poached.
1 side of bacon (grilled and fried).
100 gals. of water boiled from cold.
22 lb. of chops grilled.
67 slices of toast.
10 gals. of coffee.
2 lb. of Quaker oats.

Average *monthly* list of food prepared on the apparatus at installation "D" and consumed at other places :—

218 lb. of boiled beef.
98 lb. of roast beef.
77 lb. of boiled ham.
230 lb. of bread.
50 gals. of water boiled from cold.
50 teas.
21 lb. of beetroot.
16 lb. of cake.

A comparison of the initial costs of installations "A" and "B" with electrical apparatus, gas apparatus, and a mixture of coal, gas, and steam apparatus, is given in the following table (the cost of connecting up the apparatus to the source of supply is in each case included) :—

Installation	Electricity	Gas	Coal, Gas, and Steam
	£ s. d.	£ s. d.	£ s. d.
"A"	1,446 19 0	1,169 0 0	1,275 0 0
"B"	566 6 0	488 0 0	536 0 0
"C"	108 12 0	98 10 0	—
"D"	111 12 6	104 8 0	—

In the case of gas apparatus, the warming cabinets and portable fish fryers in installation "A" have been omitted, as it was impossible to obtain prices for them. It is doubtful, however, if they could be supplied for gas heating.

In the case of the coal, gas, and steam apparatus at the same installation, oven roasting, pastry baking, and grilling would be carried out by coal or coke (with the exception of the grills in the serveries, which would be done by gas); the hot cupboards and steamers by steam, and the remainder of the apparatus would be heated by gas.

On installation "B," under coal gas, and steam apparatus, coal or coke would be used for the treble oven range and grilling, gas for the cabinet roaster and fish fryers, and the remainder of the apparatus would be heated by steam.

The author is indebted to the Falkirk Iron Company, Ltd., for supplying the prices of the apparatus for coal, gas, and steam.

In comparing the initial costs of these installations heated by different agencies, one must not overlook the fact that the manufacturer of electrical apparatus has not the advantages of the manufacturer of either coal, gas, or steam apparatus, inasmuch as the demand for electrical apparatus is very small compared with the others; his patterns are new and the skilled labour more costly.

The difference in the initial cost is not so much with an installation of coal, gas, and steam, as with gas alone, but it would be impossible to use gas apparatus only on installation "A," for instance, owing to the

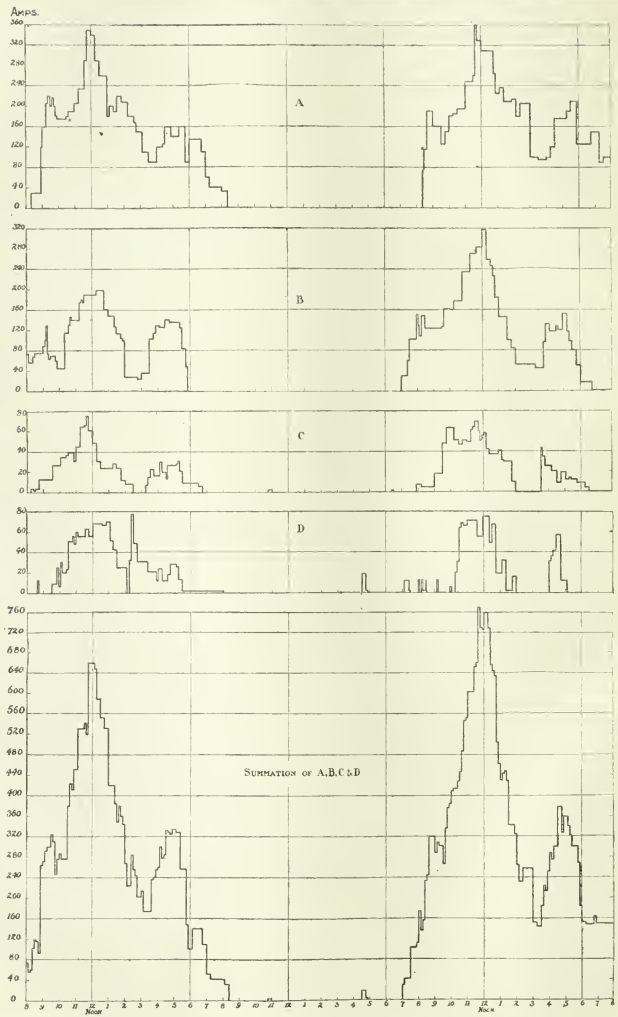

Fig. 4.—Load Curves. (The pressure in each case is 240 volts.)

restricted space. The first cost is not the only cost to be considered, and should never be looked upon as the prominent factor.

When the working comparisons are considered, electricity has the advantage in almost every detail, the following being a few of the essential items which in the majority of cases when carefully gone into offer sufficient advantages to outweigh any difference in capital cost :—

(1) Cleanliness and absence of fumes ; as against the fumes where gas is used, and the soot and smoke with coal and steam (from boiler).
(2) Constant heating value, also the facility of reducing the heat to a definite degree, which is impossible with either coal, gas, or steam.
(3) Reduced labour costs—a turn of a switch is all that is required—as compared with coal or steam ; the two latter entail increased cost for cartage of coal and the removal of ashes, also continual attention to firing, and the cost of cleaning up when either coal has been delivered or ashes removed.
(4) Less floor space required, owing to the fact that electrical apparatus can be installed in almost any position and in some cases mounted on tables or one above the other. The amount of floor space taken up with coal or steam plants is considerable, mainly owing to the boiler house, coal heap, and ash tip. Gas apparatus is not so bad in this respect, but it cannot be so conveniently installed in small places, owing to the risk of fire and need of ventilation. Less floor space also means less rent, which in some cases is an important item.
(5) Economy in food, owing to less shrinkage of meat and less waste of food, mainly with cakes, pastry, and bread, caused by unequal distribution of heat with gas and particularly with coal apparatus.
(6) Saving on the renewal of kitchen utensils. This is a very heavy item when coal is used for boiling, frying, etc.
(7) Low maintenance costs.

There are many other incidental advantages, but the above are in themselves sufficient to justify the installation of electrical apparatus.

Fig. 3 shows the lay-out of a canteen kitchen designed and in course of construction by the author. It will be observed that arrangements have been made to carry out efficiently the preparation of food for cooking by the use of auxiliary plant—meat and vegetable choppers, potato peelers, etc. The kitchen is situated between the dining rooms, the plant being designed to supply the cooked food for 1,500 persons at one sitting. Special attention has been given to ensure quick service, and the washing-up arrangements are such that plates, etc., are cleaned with a minimum of handling. The total load connected is approximately 350 kw.

The charts reproduced in Fig. 4 show the nature of the loads on the respective installations, the lower chart being a summation of the other four.

These charts of supply should be of special interest to central station engineers, as they indicate how similar installations will affect the load on their stations and networks. They also form a guide as to what one may expect in the future when the majority of large kitchens are run by electricity. In the author's opinion this is only a question of time. With the advantages of electricity in such applications, and the unity of electrical engineers, there is very little to prevent the desired results from being achieved in the near future.

The author is anxious to impress upon central station engineers the desirability of fostering the cooking load. That good work is being done in various parts of the country there can be no doubt, but he is convinced that fully 60 per cent of the large cooking business has been secured by the energies of the manufacturers. The author has prepared a partial list of these installations, compiled with the assistance of some of the important British firms. In this country there are over 400 installations with a total capacity of approximately 22,000 kw., preparing nearly 130,000 meals per day. This list is by no means complete, but these figures are a sufficient indication that electrical cooking is gaining ground, especially so when it is known that 80 per cent of these equipments have been completed during the last 3 years.

As to the future, in Newcastle district alone we have proposals in hand for cooking meals for over 22,000 persons per day, with an approximate total capacity of 4,000 kw. What is being done in one district can, to a certain extent, be carried out in another. As has already been pointed out in the paper, the development of electrical cooking depends on co-operation. Supply authorities must not expect the manufacturer to do all the spade work, or vice versa. There are many centres where a large amount of business can be secured if handled in a proper manner. A good deal of business is undoubtedly lost owing to the central station or sales engineer not having sufficient experience behind him to convince a prospective client. One cannot expect every supply company to employ a specialist in electrical cooking and heating, and the author would therefore suggest the need of an energetic and unbiased advisory committee, which would be subsidized both by supply companies and by manufacturers. The business of such a committee would be to prepare campaigns, conduct forcible demonstrations, draw up schemes for supply authorities to present to their clients, and similar duties. Such a committee must of course be run by experts, who would be of considerable assistance to its supporters, and by doing so the ground already gained would be largely extended. The appointment of such a body would give the whole industry an opportunity of benefiting by its experience.

It is, of course, assumed that the central station engineer, or the sales engineer, has a thorough knowledge of cooking apparatus and their performances before he starts his campaign ; if not, either the services of an expert must be secured, or any attempt to increase the cooking load must be postponed until he has mastered the subject. The best way of buying his experience—and it can only be bought—is to erect a trial installation where he can closely watch its behaviour : by so doing he is getting his information first hand, from which he

can lay his plans for future developments. If those engineers who have not yet attempted the large cooking business will look around their districts, they will be surprised to see the enormous amount of revenue that awaits them from large staff-feeding establishments, cafés, restaurants, etc., which will fully justify the first trial installation.

If by the presentation of these facts and figures on electrical cooking the author has stimulated interest in the minds of any members who have until now not given the matter serious consideration, he will have helped in a small way to bring that future nearer to us.

In conclusion, the author wishes to record his thanks for the facilities given him in taking photographs, etc., the loan of slides, and permission to bring certain figures before this Institution, to Messrs. Sir W. G. Armstrong, Whitworth and Co., Ltd., Swan Hunter & Wigham Richardson, Ltd., Carricks Dairy Company, The Falkirk Iron Company, Ltd., The Jackson Electric Stove Company, Ltd.; and to Mr. E. Fawssett of the Newcastle-upon-Tyne Electric Supply Company, Ltd., and Mr. W. Turner of the Newcastle and District Electric Lighting Company, Ltd., for their assistance in obtaining the current charts.

Discussion before The Institution, 6 December, 1917.

Mr. Berry.

Mr. A. F. Berry: The energy of Newcastle is reflected in many ways in the paper, and the figures given are those that one has a right to expect from that place. They have perhaps the cheapest power in the country, and they have given a lead which others may well follow. There are, however, many features in connection with the installations which savour too much of the gas and coal element. The points of most interest to engineers are the number of kilowatts installed and the current consumption per person. I should be sorry to take the figures in the paper as the last word. The author says that they require some 4,000 kilowatts to deal with 22,000 persons, which is roughly 5 persons per kilowatt. In the larger canteens, say from 300 to 400 persons, we can get down to 10 persons per kilowatt if there is a separate hot-water arrangement to bring the water up to a certain temperature before dealing with it electrically. I have taken out the cost of hundreds of thousands of meals—good square meals—and I find it is possible to get down to $\frac{1}{4}$ unit per person. The author, however, does not have to worry about that, for he says that he has only to show people that electricity will cook properly. The consumption is, however, given as approximately $\frac{1}{2}$ unit per person. For years I have been able to do it for $\frac{1}{4}$ unit, and I do not want engineers throughout the country who have much dearer coal than Newcastle to think that it is necessary to exceed that figure. The tendency to cook large joints should be corrected in large kitchens. With gas and coal-cooking there are always odours, and the grease and fat collect odours. For this reason it has been common to say that one must have a big joint in order to get the best-flavoured meat. One has only to consider a particular case to realize how wrong and unnecessary it is to cook very large joints in electric ovens. Take the case of one joint of 24 lb. in the shape of ribs of beef as against three joints of 8 lb. each into which it can properly be divided. As a large joint it is left in the oven until the middle is cooked. By that time the ends are over-cooked. If, however, three 8-lb. joints are cooked there will be much less waste of time, electrical energy, and food value. The old, expensive and wasteful methods require to be replaced, especially now that the question of saving of meat has to be considered. At the "Tricity" House, the electrical restaurant in Oxford-street for popularizing cooking by electricity, it has been noted that a considerable economy of meat has resulted beyond that called for by the Food Controller. The meat purchased between April and November has been less by 4 or 5 tons than the weight allowed under the Food Controller's regulations. At the same time one notices that other restaurants have been fined for greatly exceeding their allowance. Figures given to me from the British Electric Transformer Company's works canteen at Hayes show purchases of meat at the rate of 4 oz. per head, including bone, as compared with the 5 oz. allowed under the Food Controller's regulations. In the case of Government-owned canteens, I have made a note of the fact that makers are asked to quote for ovens to roast 8 oz. of meat per head. It is a matter of fact, and one for regret, that the average Britisher does not trouble to weigh meat either before or after cooking. If he is asked to do so he considers it an impertinent request, and that it is nothing to do with other people how much he wastes. Surely it should be possible to get people to take an interest in these matters before all of us have to tighten our belts owing to the scarcity of meat, which I can assure members will become more acute.

Mr. Berry.

Mr. W. Sowerby: Speaking as a consumer I would say that three years ago my firm began to investigate the merits of the several methods of cooking. The Newcastle-upon-Tyne Electric Supply Company was asked to furnish estimates for installing an electrical kitchen and service rooms, also the probable cost of power per person served. We adopted the proposals of the supply company, and after 12 months' working the plant has proved a great success. The figures for consumption of energy for the year 1917 are considerably below the estimate furnished by the supply company. One of the chief features of electrical cooking is the ease with which kitchens and service rooms can be kept in a sanitary condition. We have several eulogistic letters from visitors who have inspected our kitchens and still rooms. Last week we had 100 per cent more load than that for which the installation was intended, and out of one grill drawer I took over 3 lb. of clear fat; under any other system of cooking we should lose most of this, and at any rate on a coke grill the fat would all go to waste. I would warn members against giving cheap quotations for any plant to be installed; rather err on the other side. If the installation be required for 1,000 persons, estimate on a

Mr. Sowerby.

basis of 1,500. Business nearly always increases with increased facilities for coping with it. As to economy and efficiency, in spite of early misgivings, even against the warnings of electrical engineers and sub-contractors, we forged ahead, and after a year's trial we can honestly say that we are entirely satisfied.

Mr. H. J. CLARKE: I speak as a consumer, not as an engineer. I am interested in plant at Messrs. Selfridge's which at the present time caters for over 5,000 meals per day. Nearly three years ago we wished to open a staff restaurant, and the only available space did not seem, from the cooking standpoint, particularly suitable for the purpose. We had, up to then, been carefully watching the evolution of electric cooking and came to the conclusion that a very opportune moment had arrived to make a trial. It proved a great success and a few months ago we installed a second plant to take care of a "time-saving buffet." We have made great efforts to ensure the economical use of these two separate plants, and, by encouraging competition amongst the two staffs, have been able to bring our unit consumption per meal down to a figure much lower than the example quoted by the author. The actual figure for November was 0·15 unit. I might explain that having a good supply of steam in each case we have no electrically-operated water-boiling apparatus. There are, however, ranges of hot shelves which would to some extent counteract this omission.

Mr. C. G. NOBBS: I will deal with only two items, viz. running cost and maintenance cost. Running and maintenance costs should be the chief consideration, and initial cost should take second place, partly because a good many of the canteens which have been put up are under Government grants and will not have that advantage later on. It is very important, therefore, that one should know about the coal and gas and steam side as running and maintenance costs will mostly determine the system adopted, but there are very few who have brought that matter to such a basis as we electrical engineers should like to see. If one asks a man how much coal he uses in the range he is surprised and says "As much as I can get into it." An electrical engineer perhaps works out his figures with a slide rule, which the ordinary caterer would hardly be bothered with, though he is out to save as much as he can. In comparing the various installations as to running cost I think it should be understood that the duties of installations A and B are different. As to installations C and D, we have not all the particulars in the schedule to make an accurate comparison. I will first compare the running costs. In installations A and B there is a wide variation: for A it is 0·29 unit per person, and for B 0·5. But A is a restaurant and B is a canteen. To arrive at an accurate analysis the weight of food given in the table on page 99 should be totalled in pounds. Eliminate the water-heating, because in installation A we find the water is raised from 150° F. to boiling point and in B it is taken from cold. We should therefore take the weight of food only and use that as a basis to work upon. Reduce the weekly total given for A to "per day" and also eliminate water for tea, coffee, etc. Calculated roughly B will consume three times the amount of electricity for heating water from cold, so if the author has based consumption on the schedule of food and water, that would partly account for the increased cost of 0·5 for B, as compared with 0·29 unit for A. Approximately there is a total of 1,500 lb. of food for A and 680 lb. for B per day, exclusive of water. The consumption less water-boiling as given in the paper would therefore represent 380 units per day for A and 220 units for B, and the average number of daily meals for A is 1,586 against 480 for B, which works out approximately at 0·94 lb. per meal for A, as against 1·38 lb. for B. Therefore B consumes roughly 50 per cent more food per meal. Electricity consumption represents 0·23 unit per meal for A and 0·45 for B. From these figures it will be seen that there is a slight increase in the consumption of B on "lb. of food" rating; this may be due to the "several other duties" which the author mentions are performed by B. As to running cost, I understand a certain number of steamers and pans in the A installation are operated by steam, whereas in B it is entirely electrical, whether for steaming or water-boiling. What would be the proportion of the amount of steamed food at installation A? If any of the list of food is cooked by steam a further credit consumption should be given to B. In the rough calculations made I have assumed that the amount of food stated in the schedules is all electrically cooked. With regard to maintenance, one ought to be very well up in the maintenance cost of coal, steam, and gas when meeting caterers who are familiar with them, although they may not be able to quote their results. Having an extensive experience in these lines and electrical cooking, I consider the costs of maintenance given in the paper to be comparatively very low. At the author's request our "heavy" cooking department made an approximate total of its output in heavy electrical cooking plant for the last three years, exclusive of domestic cooking or heating work, or ovens for special work up to 20 ft. in length, and it was found to represent about 11,000 to 12,000 kw. capacity. The domestic side has been more or less set back during the last few years, whereas the heavy side has had an impetus. I suggest for commercial purposes and as a simple way of explaining maintenance to the prospective customer, that maintenance be quoted as a percentage of installation or apparatus cost. Installation A works out at $\frac{3}{4}$ per cent of the installation cost, and B approximately $2\frac{1}{2}$ per cent, including wiring, plant, and equipment. The variation in the percentage might be partly accounted for by the high installation cost of A compared with B. Installation A, I think, works out at about £6 a kilowatt and B at £4. It would be preferable that the author tell us the initial cost of the apparatus only in each case, reducing the special fittings of the restaurant, such as nickel-plating, which are not put into the canteen equipment. We should then get the standard cost and could base the maintenance percentage on those net figures, omitting the cost of the wiring equipment. If we include the wiring equipment, we have in the case of installation A probably three or four floors with special wiring equipment, whereas in B the whole is grouped round a central main kitchen. At any rate the wiring in B must be considerably less. As soon as we include wiring equip-

Nabbs. ment, which the manufacturer cannot very well do, we are liable to get inaccurate percentages for the ratio of maintenance to initial cost. From a rough estimate of the respective values of the apparatus, I think the maintenance cost would be $1\frac{1}{4}$ per cent per annum for A and $2\frac{3}{4}$ per cent for B. With regard to coal and steam maintenance, I give an example to substantiate why I say electrical maintenance is so small. In an hotel with 400 bedrooms they have a coal range 20 ft. by 5 ft., renewals include about $1\frac{1}{2}$ tons of metal per annum, repairs and renewals to steam apparatus, boiler, etc., average £100 per annum for the contractors, exclusive of the resident engineer's work on minor repairs. There is also far more wear and tear on cooking utensils and "hollow-ware," a not inconsiderable item for restaurant kitchens. Not nearly enough prominence is given in the paper to what in my opinion is a most important attribute or superiority of electrical cooking, viz. its low maintenance costs as compared with other methods. I suggest that the author give us a few of his meter readings of individual pieces of apparatus in relation to cooking capacity and consumption of electricity, and the input of therms in relation to output in weight of cooked food. For example, take the first item of installation A, a double-deck baker's or confectioner's oven; what are its capabilities for bread baking, confectionery, or roasting of meats, and consumption of electricity as regards output in food? Take another example, the large cabinet roasting oven, item 1 of installation B. I understand it is capable of roasting 3 to 4 cwt. of meat at one charge. How many legs of mutton will it hold, and what is the unit consumption in roasting, also the meat shrinkage and the return of fat saved? What does all this represent in money saved to the caterer? Put in figures of this form, the appeal to the prospective customer would be irresistible in the hands of a capable engineer.

Brazil. Mr. H. Brazil: This paper contains a great deal of very valuable information, but, I must confess, I was somewhat disappointed that the author gives very little information as to the details of the apparatus, particularly with regard to the heating elements. I think he is quite right in putting reliability as the first thing to be considered, as everybody will probably agree that it is a very serious offence to keep people waiting for their meals. As far as the wiring is concerned, this reliability can be easily attained by dividing the circuits up suitably, the question being one chiefly of expense, but with regard to the heating elements, the matter is not quite so simple. If we first of all consider the apparatus in which the heating element is loaded rather lightly and is clamped to the bottom of the vessel, little trouble is experienced. This is the case with hot-plates, but my own opinion of these is that they are very far from satisfactory owing to the very poor efficiency, it being almost impossible to ensure good contact between the top of the hot-plate and the bottom of the cooking vessel. On this point I am quite in agreement with the author in suggesting that apparatus should be as far as possible self-contained, that is to say, that the heating elements should be clamped to the bottom of the vessel into which the food is put. This arrangement gives much greater satisfaction than the hot-plates, not only from the point of view of efficiency, but also from the rapidity with which the heat is transmitted to the food, particularly in the case of liquids. When we come to grilling apparatus the problem is much more difficult, as the elements cannot be clamped in the same way as the others, but must remain free in air. For some three or four years past the whole of the cooking in my substations has been done electrically, and it has been extremely satisfactory, the only point on which I am not satisfied being the maintenance of the heating elements in the grills. The elements I have been using consist of strips of mica 1 in. wide, 5 in. or 6 in. long, and about 1/16 in. thick, wound with nickel-chrome wire in the form of a flat helix. These are supported only at the two ends, and when the current is switched on there is a tendency to buckle, which causes the elements either to touch some other part of the grill and thus gives rise to a short-circuit, or else by repeated buckling backwards and forwards to break the mica. The mica itself also appears after it has been in use for some time to lose its character and gradually to disintegrate. These grills are working about 6 hours per day, and the mica elements have a life of about 2 months. I have tried winding the wire loosely, winding it more tightly, and using different thicknesses of mica, but up to the present I am not in a position to say which is the best method. Just lately, being dissatisfied with the mica, I have tried some experiments with fire-clay of similar dimensions, except that it was for mechanical reasons made about $\frac{1}{8}$ in. thick. The standard mica elements were loaded to about 65 watts per inch of length, but with the fireclay elements I made the load as much as 120 watts per inch of length. Up to the present these fireclay elements show no signs of deterioration, although they have been on circuit for 200 hours, being switched off every hour and allowed to get fairly cool, and then switched on again, and cold water being thrown over them on several occasions. One little difficulty of the fire-clay is that it takes about 4 minutes to get to its proper heat, but this, I do not think, is a very grave objection. I consider this question of the details of manufacture of heating elements to be very important, and I should like to ask the author if he can supply us with as much information as possible as to the methods now most commonly in use for constructing these elements. From the point of view of the station engineer, electrical cooking is likely to be of very great service, as it provides a load at a time when otherwise the load drops very considerably, that is to say between 12 and 2 o'clock. I should say that if the curve shown by the author were superimposed upon the ordinary load curve, the result would be an almost straight line, a very desirable state of affairs. There is one other point I should like to emphasize, and that is that manufacturers must consider the question of making cooking apparatus suitable for a pressure of 400 volts. In the vast majority of cases, current is supplied on the three-wire system, and the difficulty of keeping a balance with units of 20 to 30 kilowatts, which is the load taken by large ovens, is a very serious one. Lately we have connected up a large cooking installation in the City, taking 120 kilowatts, and we have been compelled to fix a special device which rings a bell when

Mr. Brazil

the load is more than a certain amount out of balance. This of course is not a desirable state of affairs, and could be entirely avoided if the large pieces of cooking apparatus were arranged to be connected to the 400-volt supply. Most supply companies have a regulation that any motors over 4 or 5 horse-power must be put across the outers on a three-wire system; I therefore do not see that there should be any difficulty in treating ovens, and other apparatus which takes a large amount of current, in precisely the same way.

Mr. H. N. GRESLEY: There are one or two points which would be of particular interest to a railway man if the author could give us a little information upon them. I refer particularly to the cooking in the dining cars of trains. Owing to a number of very regrettable accidents which have occurred from time to time, trains have caught fire in consequence of being lighted by gas, and great pressure has been brought to bear on the railway companies by the Board of Trade to try and avoid the use of gas. Of course electricity can be substituted quite easily for lighting purposes, but the difficulty has been in regard to cooking, as all the principal trains running from London to the North in peace time are provided with dining cars. Can the author tell us whether the electrical system can be applied commercially to cooking in dining cars on trains? People do not realize the amount of work done in the kitchen of a train. On the Great Northern Railway we have kitchens about 14 ft. long by 6 ft. 6 in. wide, and in those kitchens 100 meals at one sitting are often cooked. I expect it would take a good deal of electrical energy to do the cooking, and then there is also the question of whether it is going to put great weight on the dining cars. At present these weigh something over 40 tons, and provision would have to be made for keeping up the supply of current when the train was standing. That is done now by batteries and it would probably be necessary to install large batteries.

Mr. F. H. WILLIAMS: I agree with the author that the future of electrical cooking depends to a great extent on the co-operation of the manufacturer with the central station engineer, one reason being that the apparatus once installed requires attention from time to time, which the central station man must be qualified to give. Many station engineers look upon electrical cooking on any scale as a nuisance and not as a revenue producer. I also agree with the author in regard to the essential items of the kitchen equipment, but not as to the order in which he puts them. I think they are of equal importance, for the following reasons. Nothing annoys a cook more than to find his gear constantly out of order when he wants it; nothing annoys the man who pays the electricity bill more than to have to settle a bill larger than he expects, and nothing annoys everyone more than the man kept waiting for his dinner. Reliability and efficiency can be had in any piece of apparatus by paying the necessary price and seeing that one gets what one pays for. Quick service can be had by going to the right people, that is, a firm that has had experience in laying out big kitchen equipments. I think most manufacturers aim first at reliability, leaving efficiency somewhat in the background; and as far as my firm is concerned, that is because of the cost of building apparatus combining both reliability and efficiency, which buyers are reluctant to pay for owing to the great disparity in the initial cost of electrical equipment as compared with a gas equipment. Initial outlay should not be considered altogether when putting down a new kitchen plant; to save a few pounds initially probably costs many more pounds afterwards. Running and maintenance costs should in my opinion always be the chief considerations. Further, I consider it to be essential that somebody with experience should be put in charge of the kitchen for a time to instruct the cook in the proper use of the apparatus. No doubt this will save many pounds afterwards. Regarding efficiency, I will give two instances of how current may be saved. We have made some special ovens having a cubic capacity of about $3\frac{1}{2}$ ft. The loading of each of these was 3 kw. They attained a temperature of 600° F. in 45 minutes. One hour after switching off, the temperature was 340° F., sufficient to continue cooking. The cooking temperature, 360° F., was maintained afterwards on a quarter of the heat, which is equivalent to 750 watts. This oven costs more to build than one of our standard type, slightly smaller, which with a loading of 3·3 kw. came up to 600° F. in one hour and required 1,000 watts to maintain the proper cooking temperature. Another instance was a water boiler of 6 gallons' capacity, 6 kw. loading. This was boiled from 58° F. in 29 minutes and the temperature after 12 hours was 90° F. Another boiler of the same size and loading took 32 minutes to boil, and the temperature after 12 hours dropped to 60° F. The temperature during the night had fallen to 50° F. I will give details of the running cost of two kitchens equipped by my firm. One, a staff kitchen providing 80 breakfasts, 480 dinners, 480 teas, and about 12 suppers five days a week, but breakfasts and suppers only on Saturdays. On the average there were 80 gallons of water raised daily from 100° or 110° F. to boiling point. The units consumed over a period of six months averaged 955 per week. The cost per unit is $1\frac{1}{4}$d. This kitchen has been running for two years and the user is very well satisfied. Another instance is a convalescent hospital for soldiers, providing 164 people with breakfasts, dinners, and teas, and a three-course late dinner for the staff, including boiling water for all meals. At least 36 gallons of water are raised to boiling point from cold. The average consumption is 110 units per day. This kitchen has been running for three years.

Mr. F. P. FLETCHER: The chief point on which most speakers have laid stress is reliability. That is necessarily a matter of the elements. I see no difficulty, if the elements are of mica or of porcelain, why they should not be of standard dimensions, so that one could get them from the ordinary contractor or builder or maker of the apparatus. If an element fails it seems a pity that one has to send to particular makers, or have always to keep a stock of spares. If one's lamp fails one hopes to get another from any contractor; and if electric heating and cooking are to extend, such facilities must be given with regard to the replacement of elements. With reference to quick service and efficiency, these appear to go hand in hand.

Theoretically one would expect a large oven to be more economical than a small one, and rapid heating more efficient than slow heating, yet one cannot wholly follow that rule. The equipment of a large kitchen appears to be rather analogous to the case of a central station engineer laying down his plant to meet a certain demand, where it is desirable that he should use large apparatus instead of a multiplicity of small types in order to gain every advantage. Another point which affects the central station engineer very much if electrical kitchens are to be increased, is that it seems impossible for him to continue to distribute energy at low pressure for heating. This means distribution at high pressure, with transformers at every house or hotel, if he is to avoid a heavy cost in copper. I would ask the author whether he has determined at what stage it is advisable to depart from the electric heating of water and rely on gas and oil. I am at one with him in thinking it should be done for all quantities over and above trivial amounts. From the manufacturing point of view there is another side which must be attended to, and that is the equipment of operating and controlling gear for these heating installations. I believe the operating and controlling gear has not necessarily been of British manufacture, and it is up to the switch manufacturers to show that with the advance of electrical heating apparatus suitable switchgear can be produced for satisfactorily controlling it.

Mr. W. R. Cooper: Although I appreciate the information the author has given us, I should like to see the paper more critical than it is and more after the style of the paper which he read before the Institution in 1914.* With regard to the installations, can the author describe the character of the service rendered rather more minutely? If one looks at the load curves it will be seen that the diversity factor is not very good. It looks as if the service rendered by each of the installations is practically the same. From the point of view of the electricity-supply authorities we desire the diversity factor to be large, but in the case of these restaurants it does not seem to be nearly so high as in kitchens in private houses. Then, is the plant the same in each case; that is, is it made by the same manufacturers? In the author's previous paper it rather looked as if the larger proportion of faults would be in hot-plates rather than in grills and ovens, whereas in this paper there appears to be quite a large proportion of oven and grill faults in installations B and D. With regard to wiring faults, I should have thought that present designs should be such as to keep them down to a much smaller proportion than is shown in the table. It might be an advantage to state the faults as faults per kilowatt per annum; otherwise it is rather difficult to make a comparison. On that basis, installation A is very much better, though it must be remembered it is for 10 months only as compared with one year, and such figures are only comparable after a considerable time. The figure for A is only 0·14; for B and C it is practically 1·0, and for installation D it is as high as 2·3. I would ask if the author has had any experience of radiant heat hot-plates and whether he has done anything in the way of thermostatic control, which has been introduced to some extent in the United States. I agree with the author as to the desirability of co-operation and I hope station engineers will show their willingness to co-operate with manufacturers to a larger extent than they have done.

Mr. A. Goddard: Speaking on behalf of Messrs. J. Lyons & Co., up to the present we are not users of electricity for cooking, but if it can be used for cooking with economy and good practical results, we should not be behind in taking it up. After hearing what has been said to-night I shall take more interest in electrical cooking methods than has been the case in my firm during recent years.

Mr. W. H. Wilson: In examining the chart on page 100 one cannot help noticing its peculiarity. Starting at 0 a.m. there is a steady rise of load until noon; then we have a fall which continues until 3 p.m. The same remark applies to the chart on the right-hand side. One cannot help thinking that such a chart is not one to encourage a supply company to give exceedingly low rates for current. A short time ago I read in the *Electrical Review* of a new system of cooking, practically the hay-box system, and it makes one wonder whether some such system could not be adapted to the present forms of electric cooking apparatus. It is a question for the makers as to whether they cannot so arrange their apparatus that instead of giving a peak load the load is spread out so that the consumer has the benefit of paying a lower rate than he does to-day. At the same time there is the question of economy from the meat point of view, that is, whether joints cooked more slowly do not suffer so much from wastage as when cooked more rapidly. I think the reason why we do not take so long over cooking is because of the principles on which we work—20 minutes per lb. weight of joint—but it does not follow that that is correct. That is a point which might commend itself to makers of cooking apparatus. I agree that supply companies and makers of apparatus should co-operate in furthering the interests of electrical cooking. One will find in practically every town in the country an institute or school where students are versed in the art of cooking. These schools are principally equipped with gas and coal-fired ranges. Would it not be advisable for the makers of electrical cooking apparatus and for supply companies to arrange for the equipment of these schools with electrical apparatus? In that way the student is fully versed in the advantages of electrical cooking in addition to the other two systems, so that at the end of the course he may be regarded by the public as an expert on all culinary matters. I think we need have no fear whatever as to which system of cooking would appeal to him the most, and in that way he would prove to be the best canvasser for pushing electrical cooking.

Mr. G. J. Walker: Speaking as a railway hotel manager there are one or two questions I have to ask. First, has duplication of any part of the apparatus been necessary owing to faults or breakdowns? If electrical apparatus be a success it has a large future so far as dining cars are concerned. Gas is fairly satisfactory, but one of the objections is fire and the con-

* *Journal I.E.E.*, 1915, vol. 53, p. 42.

Walker. fined space in a dining car which raises the temperature. I do not think the ventilation problem has been solved, and certainly not to the satisfaction of the chef. Has the author made experiments as to the time necessary to raise the temperature of the ovens to the cooking point, as compared with gas or coal? That is important, especially in a restaurant train. The paper deals largely with canteens in places where there is a set meal, a sort of table d'hôte served between certain hours, but in a dining car or an hotel there are meals to be provided practically from 6 o'clock in the morning until 12 at night. A coke grill is economical, as the temperature can be maintained at a low cost. As to the reduction of staff, I do not think that is going to effect a reduction of cost, because in an ordinary kitchen if one does away with an attendant one has to put an electrician in his place. I wonder if the author has any figures on the temperature of the kitchen in which the electric apparatus is installed—the highest temperature when the pressure is strongest in the kitchen. The author referred to a solid top as against rings. I think any chef would favour a solid top, because whether a range is heated by gas or by coal he gets his greatest heat in the centre, and that gradually radiates towards the edges and gets to a low temperature. With regard to his utensils, instead of moving a switch he simply pushes them off to the part of the stove which is of a lower temperature. If the apparatus could be made so that he could distribute his heat to get the high temperatures and the low temperatures where he wants them without using numerous switches requiring some time to learn how to use them, it would be an advantage. With regard to the economy in food owing to the shrinkage of meat, can the author give us figures to compare the shrinkage of meat cooked by coal and gas and that cooked by electricity? I think there is a false impression about wastage. I have frequently found that it depends entirely upon the character and class of joint and on its size, and also largely on the way in which it is cooked. No doubt a good chef could get good results either with gas or electricity. There is a point with regard to the saving of kitchen utensils, but I do not think that coal or gas affects modern nickel culinary utensils very much. They certainly do in the case of aluminium.

r. Holmes. Mr. W. H. Holmes: The ground has been so excellently covered, that as a user of electricity in a restaurant in the West End of London, in the Haymarket, I will only say that electrical cooking was installed there in December last and I have found it excellent and very satisfactory. It has effected a saving, and is in fact all that could be desired. I have no wish to change.

r. Crosbie. Mr. C. W. Crosbie: I should particularly like to draw attention to the practical importance of the similarity of the load factors in such dissimilar installations as A, B, C, and D, namely, 13, 17·8, 13·4, and 13·1 per cent respectively, or an average of 14½ per cent. The figures for installation B, however, have been worked out on 130 kw., whereas a total of 105 kw. is installed. Taking the latter figure, the load factor is reduced from 17·8 to 13 per cent, which is almost identical with that of the other installations. Most speakers have ignored the question of filling the huge gap in the load curves between the hours of 6 p.m. and 8 a.m. If we consider the table on page 98 in conjunction with the load curves on page 100 and take the ratio of the maximum demand to the number of kilowatts installed, we find that installation A gives the smallest figure; the ratios are 35, 48, 44½, and 55 per cent in the cases of A, B, C, D respectively, and shows the influence of preheating water on the maximum demand of installation A. If the maximum demand is kept down at that period of the day when the demand is being made by other portions of the cooking installation, and spread over the period when we are not doing anything, we shall not only considerably increase the load factor but at the same time be able to run some of the elements at a lower temperature. Thus we should obviate a great deal of the high maintenance charges such as we see in the paper. It will be seen that the figures of maintenance are in the order A, B, C, and D upwards. I think installation D shows a higher maintenance because it has done more work than any of the others, which is apparent from the number of units consumed per kilowatt installed, namely, in the case of installation A about 500 as against 632 in that of D. With regard to the question of spreading the load over periods when the demand is not made by the rest of the cooking apparatus, it will be generally found that all boilers, from the point of view of limiting the loading, must be allowed something like 1½ to 2½ hours for the raising of the temperature of the liquid to the necessary point, and consequently require to be switched on about this time prior to the serving of the meal. The result is that the load of the boilers comes on at a period when the rest of the cooking apparatus is also making a demand upon the mains. I have taken as an instance the 350-kw. installation mentioned by the author. There we find that a 60-gallon boiler, another of 40 gallons, six of 20 gallons, and two of 10 gallons' capacity are arranged for, giving a total of 240 gallons of water to be heated from, say, 40° F. in the case of the two large boilers, to 180° F., and in the case of the other urns from, say, 40° F. to 212° F., equivalent to a loading of approximately 55 to 60 kilowatts. From the paper it will be seen that the relation of the maximum demand, as indicated by the load curves, to the total kilowatts installed is roughly 44 per cent. In the case of the 350-kw. installation it would not be unreasonable therefore to assume that we should get a peak demand of 190 kilowatts, and 55 to 60 kilowatts is a very considerable proportion of that peak. By installing a thermal-storage system the peak would be reduced by about 45 kilowatts. It is a pity that in this 350-kw. installation the author has not given us any particulars to enable us to say whether he is doing this or not. I believe it will be generally found that the load factor will thereby be increased something like 5 per cent. It is very difficult to predict exactly what one would get: the extent of the improvement would depend on whether the maximum demand of the rest of the plant was greater or less than that of the cooking installation. From my experience * of an installation which I have

Mr. Crosbie

* C. W. Crosbie: "Electric Water Heating as applied to Domestic Service," *Electrician*, 1916, vol. 77, p. 762.

for domestic purposes in my own house I have conclusively proved that one does get a very good load factor. For instance, my lighting load factor is about 5 per cent per annum; cooking and heating load factor about 6 per cent, water heating 100 per cent, and the combined load factor is something like 12 per cent. I think the author should have gone into that point particularly, because in this installation the charges for electricity are made on the basis of load factor, and for every 1 per cent increase above a 10 per cent load factor the consumer would benefit to the extent of 2 per cent reduction in price.

Mr. E. T. Williams.

Mr. E. T. Williams: Time will only permit me merely to mention a few points and I hope that the author will reply to them. First of all on page 93, where he recommends heating water by steam, or other means, to 160° F., I should like to know how he arrives at that figure, and if steam is used, why not boil water with it instead of resorting to completing the process by electric urns? On page 93 again, it would be valuable if, in the particulars of installations given, the number of persons to be served simultaneously were mentioned. In regard to the baker's oven, it is not stated whether it is used for baking bread, and if so a statement of the number of loaves it can deal with would be useful, and so on throughout the list. Particulars of the duty or capacity of each item of plant might be mentioned. Fig. 3 on page 96 has been referred to, and as it might be taken as a working plan I may say that the architect informs me it has since been decided to remove the chef's table to the place of the wash-up table, and vice versa. I understand that most of the boiling of water in this scheme is to be done entirely by steam. On page 98 in the tabulated statement an additional column giving the cost of maintenance per meal served would be valuable. Nothing is said as to whether the meals to be provided by these kitchens are all taken at one time as in a factory, or whether they are spread over a long time as in an ordinary restaurant. If a "meal factor" could be worked out it would enable these comparisons to be more accurately judged. In the remarks at the bottom of the page, in the case of installations A and B the cost for electricity is given per meal, and in D per person. Does that mean the same thing? The overload capacity of the plant referred to in D might be valuable as enabling an unanticipated rush to be dealt with. If cooking plant can be designed which will safely cope with occasional overloads the initial cost of installations might be reduced. On page 99 the wiring faults given are very numerous, and I think the author should say what they are, in order that the causes can be ascertained and remedies proposed. In connection with high candle-power gas-filled lamps, where one gets very high temperatures our practice is to take leads from the lampholder to connections in a box a short distance away from the lamp where they join the insulated conductors. The leads from the lampholder to the connector are insulated with porcelain heads. On page 99, the comparison of the capital cost of installing plant tends to be misleading because the cost of connecting up the apparatus to the source of supply is included. If 350 kw. maximum load has to be dealt with by a works which generates its own current, that is a factor which will very considerably influence the adoption of electric heating. On the same page the author refers to the high cost of apparatus being due to the comparatively low demand for electrical cooking. I intended to bring evidence, had there been time, to show that if we wanted to get a big demand for such apparatus we must arrange for letting it out on hire to small consumers. Many works pay for their current on a load-factor basis. If the load factor of the cooking plant is less than that of the works it may tend to raise the cost of current for the whole works. We want to work out, when installing these big plants, how it is going to affect the load factor of the whole works. In some instances it might be a serious disadvantage; in others it might be a great advantage. I think a bonus to the staff might be paid to reduce the cost of current. In the North of England something happened which nobody has mentioned, and which might affect this question, namely that the cooking on Monday in the mills was exceedingly heavy, but it dwindled down till the demand for cooking on Friday was practically nil. If the electrical method could be shown to be more economical under those circumstances I think it would probably appeal to the mill managers.

Mr. E. T. Williams.

Mr. S. E. Fedden.

Mr. S. E. Fedden (*communicated*): In arranging the cabling for large installations of electrical cooking apparatus, it is the practice of my department to divide the installation into two sections, as equal as possible. This is very convenient when a two-phase supply is available. Double-pole main distribution boards are used, and each piece of apparatus is on a separate circuit, and in the case of a large oven with hot-plates this is divided into two circuits. The single-pole fuses and switches supplied by the makers are fixed in the most convenient positions for the use of the cook. With regard to the apparatus generally, I find most trouble with the enclosed type of hot-plate. I have experimented with the open type made by Messrs. Belling & Co., and find this more satisfactory than the other. I consider that the flexible metallic tubing is a weak link, as it rusts and breaks away in course of time, owing to steam and liquid. Galvanized screwed tubing would be a far more satisfactory method, but as certain of the apparatus is portable it cannot be used in every case. Accessibility of all elements appears to me to be of very great importance. I admit that in arranging the cooking apparatus of the installation in Sheffield I was somewhat in the hands of the cooks, but looking at the sketches in the author's paper I find the apparatus arranged on similar lines to ours. In one installation a service of cold water was laid to each boiling pan, water urn, stock pot, etc. In future there will be hot water, in accordance with experience gained. Returning again to the question of hot-plates, I find in hospital work, where the hot-plates are required for very short periods at different intervals of the day, the enclosed type does not compare favourably with the open type. The open type attains full heat very quickly, and is certainly more efficient. The difficulty in Sheffield has been to persuade the cooks to regulate the heat by the use of the switches, and one complaint

Fedden.

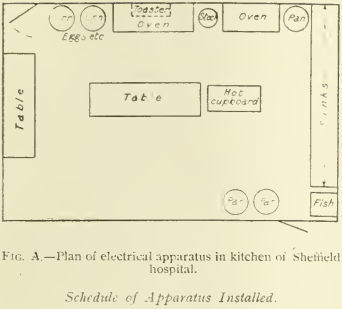

FIG. A.—Plan of electrical apparatus in kitchen of Sheffield hospital.

Schedule of Apparatus Installed.

1 cooker consisting of 2 ovens, each measuring 20½ in. × 20½ in. containing 6 boiling rings—one 12 in., one 10 in., three 8 in., and one 6 in.—grill 26 in. × 11 in., hot cupboards fitted between 2 ovens for keeping plates warm	20·6 kw.
1 roasting oven, cooking space 36 in. × 22 in. × 30 in.	7 ,,
2 12-gallon boiling pans, each 6 kw.	12 ,,
1 6-gallon boiling pan, each 6 kw.	12 ,,
1 10-gallon stock pot	3 ,,
1 fish fryer, 15 in. square	4 ,,
2 4-gallon urns, each 3 kw.	6 ,,
1 toaster cooking space, 18 in. × 12 in. ..	3 ,,
1 hot cupboard, 45 in. × 22 in. × 33 in., ..	3·5 ,,
1 egg poacher	2 ,,
1 egg poacher	1·5 ,,
	65·6 kw.

NUMBER OF PERSONS FED AND UNITS USED PER DAY.

Date	Units	Persons				
		Breakfast	Dinner	Tea	Supper	Other Meals
Aug. 8	138	163	162	163	16	—
,, 9	168	163	163	163	16	—
,, 10	151	163	163	163	16	11
,, 11	146	151	149	151	16	11
,, 12	156	140	140	140	16	11
,, 13	122	140	140	140	16	11
,, 14	131	140	140	140	16	11
,, 15	122	140	140	140	16	11
,, 16	133	140	140	140	16	11
,, 17	128	147	147	147	16	11
,, 18	129	148	148	148	16	11
Total	1,524	1,635	1,633	1,635	176	99

I received was that the oven attained too great a heat. Mr. Fedd
With regard to reliability, this, I consider, is most important, but in Sheffield where the price of gas is exceedingly low, the cost for electrical energy has to be kept as low as possible. I have installed in the Sheffield School of Cookery an electrical cooker for demonstrative purposes which is used daily. A great deal of educational work has yet to be done. Prior to the war I had a department exploiting cooking and heating, but this has had to be temporarily closed down owing to more important work. I certainly am convinced that all electricity-supply departments will require a demonstrator connected with the staff to demonstrate the economical side of electrical cooking, and also to instruct the ever-changing cooks. Prior to the war, I started a scheme for the hiring out of electrical cookers for domestic purposes, and have about 50 in use on the mains, but this again had to be stopped owing to the supply being required for munition purposes. I am of the opinion that a big future is before us in electrical cooking and heating, and that electrical cooking will become general. I am able to give particulars of an 11-day test made in August 1916 of an electrical cooking installation in one of the Sheffield hospitals. The total capacity of the installation is 65·6 kilowatts, and the arrangement of the electrical apparatus is shown in the diagram herewith (Fig. A).

The following is typical of the cooking which is carried out day by day, and is a copy of the record sheet dated 12th August.

Number for breakfast	140
,, dinner	140
,, supper	16
,, late dinner	3
,, of night nurses	4
,, ,, (breakfast) ..	4

Food Cooked.

2 lb. peas	2 lb. mutton chops
42 lb. cabbage	1 Swiss roll
30 lb. mutton	94 lb. potatoes
7 gallons milk pudding	54 lb. beef
3 gallons porridge	16½ lb. fish
stock pot on 12 (noon) to 4 p.m.	96 pints cocoa
	1 tin tea-cakes
ham boiler, 4 hours	10 tea urns
2 tins rock cakes	4 lb. sausages
2 lb. currant cakes	7 lb. potatoes
2 lb. peas	16 fruit tartlets

In the above list the cooking was carried out entirely by electricity, the average daily consumption was 138½ units, and the average number of persons catered for was 149 per day. The consumption of energy per person served, including staff, was thus 0·29 unit per meal, or 0·93 unit per person per day.

Mr. W. A. GILLOTT (*in reply*): In replying to the Mr. Gillott discussion, I must express my appreciation of the way in which members have discussed the paper. When I prepared the paper I carried the subject to a certain point, so that members who wished to go further into

Gillott. details could by their remarks considerably increase the value of the paper. I am also grateful to those users of electrical cooking apparatus who have contributed, in no small way, by giving their own experience with the plant under their care; their remarks are very valuable and will undoubtedly be of considerable assistance to central station and sales engineers when negotiating business of this class. While agreeing with Mr. Berry that electricity is cheap in Newcastle-upon-Tyne, there are many towns where lower rates are in force. I do not consider it to be necessary to quote a very low tariff for electricity for *cooking* purposes; with current at $\frac{3}{4}$d. per unit it is a sound commercial proposition, as Mr. Sowerby pointed out. They have found, after comparing results with their previous gas bills, not only that electrical cooking costs less than they were willing to pay for the work performed, but that the comparative cost was less, i.e. with gas at under 2s. per 1,000 cubic feet and electricity at $\frac{3}{4}$d. per unit, without taking into consideration the many advantages secured by cooking electrically. In giving the approximate figure of 4,000 kw. for catering for 22,000 people, it must not be overlooked that this load is split up into several installations, and not only covers cooking but also the provision of hot cupboards and serveries. At installation A, although the hot cupboards and serveries are included under the present working conditions, they cater for approximately 9 persons per kilowatt installed, and on busy days this has even gone up to 15 per kilowatt; also the figure of 0·20 unit per person includes the current consumed in the serveries for keeping food, etc., hot. The figure given by Mr. Berry of 0·25 unit per person therefore compares very well with these, but not so well with installation B, as in this case there are really only two set meals per day, so that the apparatus has not the working advantages of installation A.

Mr Sowerby's remarks inspire confidence and really show what can be done by installing electrical cooking plant. I agree with him in the advantage of saving fat from grills and with his policy of providing for extension of business after the kitchens have been electrified and become known to the public.

The particulars given by Mr. Clarke in regard to number of units per head are very interesting, but without knowing what is actually being carried out one cannot make a comparison. His statements as a satisfied user are interesting; they also bear out the contention that after electrical cooking apparatus is installed the business considerably increases.

I agree with Mr. Nobbs that very few caterers know exactly how much it costs them to run their kitchens when using coal, gas, or steam. They may know the fuel cost, but when the whole question is carefully gone into they are generally surprised to find what they are actually paying. The maintenance figures given were submitted to a firm of engineers who carry out the maintenance of gas, coal, and steam kitchens, and they assured me that the electrical maintenance costs were very reasonable. The careful way in which Mr. Nobbs analysed the maintenance figures of installations A and B proves the case of electrical apparatus. It is, however, difficult to give a maintenance figure as a percentage of the initial cost, since some kitchens carry out a good deal more work than others, which of course affects the cost of maintenance; hence my method of giving it as the cost per 1,000 units consumed. The difference in cost per person at installations A and B was also well analysed by Mr. Nobbs, but I should like to add that installation A differs from B inasmuch that installation A provides meals from 9 a.m. to 8 p.m., and B only two set meals per day, which also accounts for a somewhat higher consumption. Installation B could easily provide for 50 per cent more meals at a very small increase in consumption on account of this. Mr. Gillott.

I purposely left out the details of construction, as it would have entailed a very long paper to have dealt with it together with the performance of the plant. I would suggest, however, that Mr. Brazil would no doubt get better results with his elements if he purchased them from the makers of the apparatus instead of experimenting with them. It is well known that two pieces of apparatus may look identical in every respect, but their behaviour on circuit be totally different. I agree with him that mica for grills is not the most suitable element former; the watts per square inch must be carefully worked out or one may get high temperatures with a consequent short life, or lower temperatures with poor grilling results. Personally, I have found fireclay formers to be lower in maintenance costs than mica (see grill faults in installation C, compared with those of A, B, and D). I sympathize with Mr. Brazil in his difficulty to obtain an even balance on the network or on the central station. It is quite possible to make apparatus for 400 to 500 volts, but the sanction of the Board of Trade must be obtained; also, one cannot get the desired regulation of heat on the smaller hot-plates. I am of the opinion that the best results are secured on single-phase systems, where no balance is necessary, and the distribution of electricity can be better dealt with by transmitting at high tension and transforming down to, say, 200 volts at suitable intervals.

Mr. Grisley raises an interesting point regarding dining-car kitchens on trains. Of course the question will be more easily solved when main lines are electrified, which, unfortunately, may not be for some time, but come it must. There are several methods that could be adopted for electrical cooking on trains. I do not see any reason why a special car should not be attached to the tender, containing a steam generating set (steam being safer than paraffin) and supplying current for both cooking and lighting. It would not add much weight to the train or overtax the boiler; the maximum demand for cooking would not exceed 30 kw., which is quite a small matter. Another method would be to provide batteries and arrange that the rate of discharge be retarded by coupling up a dynamo to the battery circuit. The batteries could also be "boosted up" at stopping places. The maximum demand could be kept low by preparing soups, etc., before leaving the starting station, and keeping them in well-lagged utensils to retain the heat. Hot water could be taken on board, and kept hot by an immersion heater or circulator. Schemes have been designed

Willott. for dining-car kitchens, and had it not been for the war we should have seen some in operation.

I agree with Mr. F. H. Williams that the apparatus once installed should receive periodical inspection and should preferably be carried out by the central station department. I am also in agreement with him that, when the apparatus is installed, a competent cook who thoroughly understands electrical apparatus should be put in charge in order to instruct the kitchen staff in the most economical means of using the apparatus. Mr. Williams' remarks regarding the efficiency due to better lagging and construction are quite interesting and prove that a little extra money spent in construction is easily recovered in the saving on running costs.

Mr. Fletcher raises an important point, namely, standard dimensions for oven and grill elements, and I quite agree with him that there should be no difficulty in constructing apparatus with busbar terminals of definite dimensions, so that replacements could be obtained as simply as purchasing lamps. Care would of course have to be taken regarding the loading of each element. The point which he raises in regard to the stage at which one should depart from electrical heating and adopt some other method of boiling water, is a difficult question to answer unless specific conditions are given. The difference in the price of various commodities would have to be known before a definite statement could be made; but where large quantities of water are required, it is preferable in the majority of cases to use a coke boiler.

I agree with Mr. Cooper that the diversity factor of cooking installations in a restaurant is not so large as in a private house, but one must not forget that a considerably better load factor is secured. The wiring faults are all minor faults, mainly caused by breakdown of the insulation. The faults were given specially to enable the manufacturers to see on what class of apparatus the highest percentage of faults were found, so that they could improve the manner of construction to obviate this difficulty. I have tested several types of radiant heat hot-plates and find that for quick boiling purposes they are satisfactory, but I am not yet convinced as to the desirability of using the same plates for simmering unless an entirely separate winding is provided, owing to the fact that by arranging heat regulation on the one set of windings the size of the wire becomes very small and the wire has consequently a short life. I have not carried out many tests with ovens having thermostatic control, but I really think they would not be of much use, as with an oven controlled in this manner it is only possible to cook one class of food per charge, owing to different foods requiring different temperatures and times for cooking.

I am very glad to hear that Mr. Goddard proposes to look into the question of electrical cooking apparatus at Messrs. J. Lyons & Company's shops. The results obtained in various parts of the country, from which many speakers have given their experience in the discussion on the paper, should inspire confidence in Mr. Goddard to install electrical apparatus. I should be very pleased to assist him in any of his specifications.

Mr. Wilson in discussing the load curves appears to Mr. Gill be astonished at the manner in which the load comes on, but on a large installation is it not exactly what one would expect for the cooking to start in the early morning? It is found in Newcastle that the cooking peaks come on at a time when the power load is dropping, thereby tending to flatten out the station load-curve. We therefore find considerable encouragement in pushing electrical cooking. While agreeing that certain cooking can be carried out under the thermal-storage principle or hay-box cookery, it is very doubtful whether we should gain much by introducing this system, as in the majority of cases chefs prefer apparatus that quickly responds to an increase or decrease in temperature.

In reply to Mr. Walker, it has not been arranged to adopt duplicate wiring for apparatus as a safeguard against breakdown. Although I have installed a large number of electrical kitchens, I have never yet seen a kitchen that has been seriously inconvenienced due to a fault. The apparatus is so designed and set out that if a fault develops it is isolated to an extremely small part of the apparatus. I agree with Mr. Walker that electrical cooking apparatus has a big future and should be used in dining cars on trains, and that gas is very unsatisfactory owing to the risk of fire and the high temperature of the kitchen. The heating up of an oven is merely a question of design Ovens can be heated up in any period from 15 to 35 minutes, or in some ovens (particularly the baker's type) as much as $1\frac{1}{2}$ hours is sometimes allowed for heating. I am sorry that I cannot agree with Mr. Walker that a coke grill is economical. Tests have been carried out in many places where it is proved that the electric grill not only gives better service than the coke grill, but actually brings an increased revenue to the user instead of extra cost. This is mainly owing to the fact that the whole of the fat is saved, and that when the grill is not required it can be switched off. It may interest Mr. Walker to know that in Newcastle-upon-Tyne, where we have a large number of electrical kitchens in addition to private house installations, two men are sufficient to keep over 200 installations in repair; therefore, it is not necessary to have an electrician for one hotel so far as the cooking is concerned I quite agree that a chef prefers a solid top for boiling purposes. The point I wished to emphasize was that unless a large amount of work is to be carried out on a boiling table, it would be cheaper from a running-cost point of view to use circular hot-plates and to switch off when the plates are not required, instead of, as with a solid top, keeping the current on and moving the utensil only.

From various tests that have been carried out I find the loss due to shrinkage when meat is roasted in an electric oven varies from 10 per cent to $17\frac{1}{2}$ per cent, with gas from 22 per cent to 35 per cent, and with coal from 30 per cent to 40 per cent. It may be interesting to mention a test which was recently carried out by one of our consumers:—

Weight of Joint (Ribs of Beef) Uncooked	Weight of Joint Cooked	Method of Cooking
$23\frac{1}{2}$ lb.	18 lb.	gas
23 ,,	$20\frac{1}{2}$,,	electricity

Mr. Gillott. This clearly shows that the shrinkage in cooking joints by electricity is much less than when cooking by gas. At this installation the proprietor estimates that he would save £120 per year on his butcher's bill due to this.

The statements of Mr. Holmes as a user are very valuable and prove that after the apparatus has been used the advantages are such that caterers have no desire to change back to the old method of cooking.

Mr. Crosbie raises the question of filling up the gaps in the station load between 6 p.m. and 8 a.m. This, of course, can be carried out by many other applications, one of which is the use of electricity in bakeries. His remarks on water-heating are extremely interesting, but he must not overlook the fact that a considerable amount of boiling water must always be ready, especially at a restaurant which is catering for a large number of customers, and this must be provided for. The comparatively high cost of maintenance on installation D is mainly due to the apparatus being overloaded. Had it been possible to have catered for these persons in two or three batches, the results would probably have been different. In the installation illustrated in Fig. 3, advantage has been taken of steam which was available for heating and boiling water. The 40- and 60-gallon pans which Mr. Crosbie refers to are for soup-making, and not water-heating.

In reply to Mr. E. T. Williams, the reason why water is only preheated to approximately 160° F. is because if it is kept in large quantities above this temperature it becomes "flat" and it is not possible to obtain such a good brew of tea as when tea is made from freshly boiled water. The loading of the apparatus as given in the Schedule indicates the maximum load of each piece of apparatus, and if all its switches were in the "high" position the stated loading would be placed on the mains; it does not necessarily mean that this quantity of electricity would be required to continue cooking, because as soon as the desired temperature is reached certain sections of elements are cut out by operating or regulating switches. The question of tabulating the maintenance cost per meal would be very difficult, as a true result could not be given owing to the fact that in every case more meals are provided than are actually partaken of. The charts prove that the load factor on a canteen is quite good, and owing to the nature of the load should be of assistance in securing a better price for current when supplied on a load-factor basis. Mr. Gillott.

I agree with Mr. Fedden that the majority of faults are met with in the enclosed type of hot-plate; that was my reason for reducing the number of such plates as far as possible. Flexible tubing is also being eliminated so as to prevent moisture impregnating the wiring. The accessibility of all elements is of considerable importance, and in the majority of cases no difficulty is now experienced in this respect. The particulars of the tests which have been carried out by Mr. Fedden are extremely useful. These tests also prove my contention that one obtains a lower average cost per person when several meals are provided throughout the day than in installations where only one and sometimes not more than two set meals are arranged for. I am sorry I cannot discuss whether the details in the lay-out of the hospital kitchen at Sheffield can be improved upon as the adjoining rooms are not shown. The position of the serveries, etc., makes a considerable difference as to how the apparatus should be arranged.

ELECTRICITY SUPPLY IN DUBLIN AND THE SURROUNDING DISTRICTS.

By W. Tatlow, Member.

(*Paper received* 15 *October*, 1917, *and read before the* Dublin Local Section, 9 *November*, 1917.)

It is universally felt that we stand at the present time at the opening of a new era and that after the war we shall have to face different conditions, necessitating more strenuous efforts but at the same time providing larger opportunities for trade and industry. All are agreed that the inhabitants of our islands must never again allow themselves to be entirely dependent on external sources for essential necessities, especially in regard to material required for national defence, and very many things must therefore in future be made at home which we have been content hitherto to purchase abroad.

We look, however, for some better return for the vast sacrifices entailed by the war than an increased activity of trade and manufacture. Should the common sufferings of our people fail to achieve a more kindly feeling between man and man, and a larger measure of mutual respect and consideration between all classes of the community, we shall have nothing worthy of the name of compensation and only a doubtful chance of attaining a really successful revival of our industries.

Any increase in industrial activity under modern conditions produces a demand for electrical power in large quantities and at reasonable cost; the time is therefore appropriate for considering how we stand in the Dublin area in regard to the vital matter of electricity supply.

It will be most unfortunate if the mutual jealousies of the various public bodies hamper the development of a suitable scheme for supplying the whole area which shall be adequate to the immediate needs and elastic in regard to future requirements. Just as a town-planning scheme is desirable in order to mould and control the extensions and reconstructions of a city, so some well-considered scheme of electricity supply, which may be gradually carried to completion as circumstances permit, should be planned for a district such as we are considering, otherwise much capital is sure to be wasted.

The Dublin area may be said to comprise the whole of the thickly inhabited country along the sea coast from Howth in the north to Killiney in the south, including the residential districts of Dundrum and Foxrock.

There are at the present time in this area three local authorities giving a public supply of electricity, namely, the Dublin Corporation and the Urban District Councils of Pembroke and Rathmines. The Urban District Councils of Blackrock and Kingstown are in possession of Provisional Orders not yet in use.

There are, however, in addition to the above undertakings three generating stations for supplying power to electric tramways, namely, the Dublin United Tramways Company's power station at Ringsend, the Great Northern Railway Company's power station at Sutton, and the Dublin and Lucan Electric Railway Company's power station. The Dublin Port and Docks Board also have a power station for the supply of light and power along the quays.

It is obvious that there is a superabundance of generating stations, and that, having regard to the total output, the generation of electric power should, for the sake of economy, be concentrated in one or at most two power stations in which advantage could be taken of the lower capital cost and greater economy in fuel and labour that accompany the use of large turbo-generators. Moreover, the diversity factor of the various classes of demand would have a favourable effect both on the capital charges and on the running costs. The latter point may be exemplified by the fact that the tramway companies experience exceptional demands on the public holidays, the very days on which power for industrial purposes is least required.

Although there is at present in and around Dublin a considerable aggregate load of electric motors, these are mostly on the premises of small consumers, and the large power users are still almost untouched and cannot be reached until power can be offered on very much more liberal terms than are possible under present conditions.

In the case of new factories it should not be necessary to reach a very low figure for electric power in order to induce the owners to take a supply from the mains, and the present rates would in many cases be satisfactory if all the factors in the case were duly considered. It is well known, however, that manufacturers as a rule greatly over-estimate their probable consumption when computing the prospective cost of electric driving, as is shown by the agreements they are willing to enter into for a supply on a sliding scale.

The concentration of generating plant as above suggested will, the author believes, admit of the sale of power at a price which will attract the large power users, and this will be of general advantage to the city, as the cartage of coal through the streets and the pollution of the air by smoke will both be reduced and the present consumers will benefit from the reduction of charges both for light and for power. Whether any actual economy in the quantity of fuel used is possible by replacing steam engines of 200 to 300 h.p. by electric driving will probably depend on the economies inherent in electric driving, owing to the use of a number of

separate motors in place of a single engine, rather than on the thermodynamic efficiency of a large steam turbine as compared with that of a reciprocating steam engine of 200 to 300 h.p. in average condition. For smaller powers the competition is between the gas engine and the electric motor. Considerable practical experience has already been obtained on this subject, and electric driving can hold its own in Dublin against gas engines at the prices ruling before the war.

The possibility of cheap generation is of course largely a question of load factor. In considering the effect of load factor the annual load factor, which is the figure commonly quoted, is the best criterion in regard to capital charges, as plant and mains must be provided to meet the maximum load which may occur at any time during the year; labour must also be provided to an extent adequate for this maximum demand.

In regard, however, to fuel consumption, which has now become a very important item, amounting to from 70 to 80 per cent of the total works costs in the case of large stations at the present time, it is the load factor obtaining during each particular period of the year that controls the fuel economy, and the annual load factor is not necessarily a measure of the average conditions.

The daily load factor is obviously very unfavourable in the city of Dublin during that portion of the year when the shop and office lighting overlaps the power load for a very short time, and it will be interesting to learn how the recent change to Greenwich time has affected the conditions. The nature of the lighting demand in Dublin is such that there will always be a very pronounced peak between 4 p.m. and 6 p.m. in the winter season, and means must be sought to minimize as far as possible the uneconomic effects of this short-hour demand.

As far as the generating plant is concerned, the modern steam turbine with low capital cost and large overload capacity fairly meets the case, and it is to the boiler house that attention must be devoted in order to minimize the heavy losses due to the use of boilers for only 30 or 40 minutes during the 24 hours.

There seems to be some hope that a boiler of the Bonecourt type, having a small water capacity for its rate of steaming and capable of being effectively lagged all over, will, when fired with liquid fuel, offer a reasonable solution of the difficulty, provided that such boilers can be constructed of sufficient size and prove durable in use. The consumption of oil might be economized by heating the oil-fired boilers to nearly the working temperature by means of steam from the coal-fired boilers before the peak of the load comes on. It is claimed that over 90 per cent of the heat of combustion of the oil can be transmitted to the water in boilers of this type fitted with economizers. As such boilers can be got under steam very quickly, they would also be of service in dealing with the occasional heavy demands produced by sudden fogs or rainstorms which are liable to occur without much warning at any period of the year.

The changes which have taken place in the load factor and maximum load of the Pigeon House station in recent years are given in the following table.

	Load Factor	Maximum Load in Kw.
Year ended March 1911 . .	13·96	4,545
,, ,, 1912 . .	13·89	5,510
,, ,, 1913 . .	13·57	6,379
,, ,, 1914 . .	13·09	6,976
,, ,, 1915 . .	14·51	7,486
,, ,, 1916 . .	16·28	7,228
,, ,, 1917 . .	15·97	7,600

The figures show a gradual improvement in the load factor in recent years, though less in amount than might have been expected.

The changing over of small existing power stations to work on a bulk supply given from an outside source generally meets with considerable opposition, partly from the vested interests of officials and partly from the desire of local councillors to keep as much authority and patronage as possible in their own hands. It can, moreover, generally be shown that at any particular stage it is cheaper to extend the existing plant than to change over to a bulk supply, although the argument would not hold if applied to a series of extensions which are ultimately inevitable.

The question of the relative economy of small stations as compared with bulk supply has been discussed in detail in a paper read at a meeting of the Incorporated Municipal Electrical Association by the borough electrical engineer of South Shields.* This paper seems to show that as a rule it is under the present conditions desirable to change over to bulk supply if the smaller station is below 2,000 kw. capacity; but needless to say every case requires consideration on its merits, such factors, for example, as the working of refuse destructors in conjunction with the power station affecting the decision in many cases.

Where distribution has been carried out by continuous current the change-over will be more costly and the results obtained less satisfactory than where the distribution has been on the alternating-current system, and for this reason the author believes it would be a distinct misfortune if continuous-current networks were now to be laid down in any further portions of the Dublin area.

Fortunately the scheme of distribution in the city of Dublin is in accordance with the best modern practice for a large district, namely, a three-phase four-wire system, and the reasonably high pressure of 5,000 volts used for the feeders to the substations enables a heavy load to be provided for at any point without undue cost. The provision of power for certain munition works illustrates this feature of the system, as it would have been scarcely practical to meet heavy loads at such outlying positions if the city had been laid out for continuous-current distribution.

In support of the argument for centralizing electric power production on the score of fuel economy alone, it may be pointed out that reciprocating steam sets of from 250 to 500 kw. capacity will under the best conditions take from 16 to 20 lb. of steam per kilowatt-hour and may very easily take considerably more if

* H. S. ELLIS: "The Generation of Electricity on a Small Scale or Bulk Supply." *Proceedings of the I.M.E.A.*, 1916, p. 100.

slightly out of adjustment; whereas modern turbo-generators of from 3,000 to 5,000 kw. should not take more than 13 lb. of steam per kilowatt-hour over a large range of load.

The economy of turbines either in steam consumption or capital cost does not seem to increase very much above 5,000 kw. until the size is large enough to warrant the construction of compound turbines, and as an example of the latter type of machines it may be mentioned that the 30,000-kw. compound turbines recently built for the Interborough Rapid Transit Company of New York showed a consumption of 11·20 lb. of steam per kilowatt-hour at their most economical load of 25,000 kw., this being equivalent to a thermal efficiency of 24·8 per cent. These machines cost £1·8 per kilowatt, whereas the 7,000-kw. reciprocating engines which they replaced cost £8 per kilowatt and used 17·3 lb. of steam per kilowatt-hour.

In addition to the advantages of large turbo-generators in regard to steam consumption, labour, and lubricating oil, a large station has advantages in the boiler house as the overload capacity of a number of boilers can cover the failure of a single unit.

It may be said that modern oil engines may be used to replace or to supplement steam plant in small stations. Undoubtedly, remarkably good results have been obtained in some places by the installation of oil engines. The author is, however, of opinion that taking into account the very high capital cost of these engines, their apparent liability to break down, and the want of experience as to their probable life, a bulk supply, even if it entails the use of rotary converters or motor converters, will generally prove a better proposition.

It will probably be quite freely admitted that a supply from a single large station is the ideal solution for the Dublin district. How or to what extent this can be realized remains to be seen.

The only large stations with reasonably good facilities for obtaining coal and condensing water are the Pigeon House station of the Dublin Corporation and the power station of the Dublin United Tramways Company, and either body would be quite capable of carrying out the project of a bulk supply. Unfortunately the Tramways Company is restrained by Act of Parliament from selling electric power. The Dublin Corporation would therefore seem to be under a moral obligation to carry out a scheme of bulk supply if pressed by its neighbours, as it has been instrumental in preventing the Tramways Company from giving a public supply, which the latter company could easily have done in the districts adjoining its extensive system.

A precedent for such an undertaking being carried out by the Corporation exists in the case of the Vartry water supply, which they maintain throughout an area more extensive than that now under consideration to the great advantage of the districts served.

The unhappy selection of the Pigeon House site militates against the success of such a scheme, the very essence of which is delivery in bulk at the lowest cost attainable. The outlying position of this station is, however, to some extent discounted by the success which has been obtained with modern high-pressure cables—the Newcastle-upon-Tyne supply system which now extends over an area of 1,400 square miles and generates about one-fifth of the total public supply in the United Kingdom uses 20,000-volt cables to a very considerable extent and with great success.

The capital already expended at the Pigeon House station is too great to be abandoned unless some radical improvement in the whole method of generating electric power became available. Such a change might occur if the distillation of coal for the production of smokeless fuel and by-products was undertaken in Dublin on a large scale.

This is not a fanciful idea, for in October last a company approached the Corporation of Brighton offering them the surplus gas from the distillation works, which they propose to erect beside the electricity supply station, to the extent of 4·8 million cubic feet of gas per day at 1½d. per 1,000 cubic ft., the calorific value of the gas being 300 therms per cubic ft. The price charged was based on coal costing 20s. per ton and was to be subject to a variation of 5 per cent for each 1s. fluctuation in the price of coal per ton. The gas was to be used to the greatest extent practicable instead of coal to fire the steam boilers in the electricity works.

The same company has entered into an agreement with the Yorkshire Electric Power Company to supply gas for firing the boilers in their power house.

The present practice seems to be to use gas-fired boilers driving steam turbines rather than gas engines if the generating plant is of large size. No doubt the lower capital cost and greater reliability of the steam plant in large units more than counterbalance the somewhat higher thermal efficiency of the gas engine.

The gain in efficiency by using gas engines is less than might be supposed unless the engines are run well loaded at all times, as the turbine maintains its efficiency over a large range of load, whereas the efficiency of the gas engine falls off rapidly as the load diminishes. It, however, the waste gases are given off at a uniform rate, the maximum power that can be obtained to meet the peak of the load may be the chief consideration, and under these circumstances the gas engine would come out the better.

The Pigeon House site is not unfavourably situated for the supply of the Southern districts. The construction of a bank slightly over a mile long from the Pigeon House to a point near the Martello Tower at Sandymount would provide a comparatively short route for cables to supply Blackrock, Kingstown, Dalkey, and Killiney, and would at the same time reclaim some 400 acres of land from the sea. This scheme would, if carried out, provide ample land suitable for allotments for the artisans and workmen of the Ringsend and Irishtown districts.

The probable demands for electricity in the Southern districts are shown in the following table, which has been based on the consumption per head of population, using the figure for Rathmines and Rathgar, namely, 23 units per head per annum. It seems unlikely that any larger demand would be made unless industrial enterprises were started in Blackrock or Kingstown where they are badly needed.

	Area in Acres	Population	Estimated Number of Units, in Millions per Annum	Estimated Maximum Load, in Kw.
Blackrock ..	1,078	9,161	0·21	124
Kingstown ..	905	16,941	0·39	230
Dalkey ..	592	3,536	0·081	48
Killiney and Ballybrack	1,016	2,721	0·062	37
Total ..	3,591	32,359	0·743	439

It may be mentioned that in Pembroke industries are carried on to some extent in the Ringsend district, and in consequence of this the annual consumption amounts to over 28 units per head of population.

The districts of Dundrum, Stillorgan and Foxrock could be provided for by laying a cable along the route of the railway from Harcourt-street, and as the maximum load would be unlikely to exceed 60 kw. for some time, the power might be conveniently taken from the nearest city transformer station. A considerable amount of building has been done at Foxrock in recent years, and it may be regarded as a progressive place in which a lighting load would be quickly acquired.

The reasons which induced the Dublin Port and Docks Board to erect their present power house are not obvious. A substation with rotary converters or motor converters fed from the Pigeon House would have provided continuous current for the cranes and other motors with a very much smaller expenditure of capital, and current could undoubtedly have been supplied from the Pigeon House at a lower rate than the cost of generation in this small steam station. Although the load factor is low, it is reasonable to suppose that the maximum loads are not due to lighting and do not necessarily coincide with the peak load of the city.

Should it be decided to convert this station into a substation purchasing power from the Pigeon House, it is worth considering whether a tunnel should not be constructed under the river near the end of the South Quays to carry across the high-pressure cable from the Pigeon House, and also to provide for the continuous-current cables which the Port and Docks Board at present maintain in the bed of the river; and, further, whether this tunnel should not be made a subway for foot passengers in order to enable the working men of Ringsend to get quickly to and from their work on the North side of the river.

The time may not be distant when even the flour mills in Dublin may find it advantageous to adopt electric driving; this would involve an extremely low rate of charge for consumers whose load factor approached 100 per cent, and such a rate might be possible if waste gases from a coal distillation process were utilized at the power house.

The author must not be taken as expressing a definite opinion that the Pembroke and Rathmines electricity works should be converted into substations supplied in bulk, but he believes that there is certainly room for co-operation, especially in the case of Pembroke. He is not an advocate of municipal trading, but in regard to the electricity supplies hitherto mentioned, he believes the Dublin Corporation to be in the best position for carrying out a good scheme. If the extensions were made gradually and were shown by results to be financially successful, enabling the cost of electricity to be reduced in the city itself, it should be possible to find means to finance the extensions without any undue risk to the ratepayers. The present financial position of the undertaking is not nearly so black as it is sometimes painted. Some of the older loans are very nearly paid off, and the loans raised in recent years should be considerably more productive than much of the outlay on the original Pigeon House scheme.

The engineers who are responsible for the power station must be congratulated on the immunity from interruption which has characterized the undertaking in recent years. Reliability is perhaps the most important consideration from the manufacturer's point of view, as even a few minutes' stoppage means a very considerable financial loss in a factory employing many hands.

The question of power for electric traction remains to be considered. There are at present two small and therefore inefficient steam power stations at work, namely, the Sutton power house of the Great Northern Railway Company, and the power house of the Dublin and Lucan Electric Railway Company situated about half-way between Dublin and Lucan. There can be no question of the desirability of shutting down both these stations. The author believes the Dublin United Tramways Company to be the body best fitted to undertake the general supply of current for traction, and he considers that they should be relieved as soon as possible of all legal restrictions in regard to the sale of electricity for this purpose.

The Tramways Company generate high-pressure three-phase current at 25 periods especially suitable for the working of rotary converter substations, and they have an extensive system of ducts into which the necessary cables could be drawn without breaking up the streets or incurring very much expense beyond the mere cost of the cables.

Mr. Tierney has shown in a paper recently read before the Dublin Local Section that at present it costs the Dublin and Lucan Electric Railway Company 5·05d. per car-mile for electric power, as against 2·67d. per car-mile if power could be bought at 1·5d. per unit, the difference in the cost of working amounting to £1,400 a year.

Overhead wires might well be used for carrying high-pressure three-phase current to both the above-mentioned power houses along that part of each route which lies outside the city boundary, and this would reduce the necessary capital outlay to quite a practical figure in each case.

The case of the Dublin and Blessington Tramway requires immediate consideration, as the concern is

run at a loss, which has to be made good by a heavy charge on certain portions of the county. Mr. Tierney has drawn attention in the above paper to the undue cost for fuel and oil on this line, amounting to 10·3d. per car-mile, and has pointed out that electrification would show a saving which he places at £2,470 per annum. A very considerable sum would, however, be required to electrify the whole of this line which is 21 miles long, even if power for working the line could be purchased from an external source, and it is doubtful whether additional traffic could be created sufficiently rapidly to make the change a financial success. A possible way out of the difficulty has been suggested, namely, that that portion of the line, some 4 miles in length, between Terenure and Tallaght should be electrified and a fairly frequent through service maintained between Tallaght and Nelson's Pillar. The would indicate that some such scheme must come into being in the near future, and such schemes have already been started at Orentano in Italy and elsewhere.

Power generated on the central bogs would be sold to the best advantage at places remote from the sea, but in order to obtain a sufficiently large load shortly after the station was started it would be almost essential to sell some of the power in the Dublin district, and the existence of a co-ordinated system of supply in the county of Dublin would greatly facilitate the ultimate disposal of a bulk supply from bog stations.

The author looks forward to the establishment of a high-pressure distribution system throughout the country fed by power stations erected on the bogs and by such water power as can be developed at a reasonable cost. The water power should be used at all times to the fullest extent available and the

TABLE OF ELECTRICAL UNDERTAKINGS FOR LIGHT AND POWER.

	Population	Approximate Capital Expenditure	Millions of Units Sold per Annum	Kw. of Plant in Station	Max. Demand in Kw.	Load Factor per cent
Dublin	304,800	£857,000	10·338	12,000	7,228	16·28
Rathmines	42,000	£135,000	0·966	1,150	566	19·5
Pembroke	25,000	£103,432	0·939	1,000	496	19·3
Port and Docks Board Power Station			0·529 (generated)	675	450	13·4

POWER STATIONS FOR TRACTION.

	Millions of Units Generated per Annum	Kilowatts of Plant	Maximum Load in Kilowatts	Load Factor, per cent
Dublin United Tramways Company's Generating Station ..	13·5	5,800	3,600	42·8
Dublin and Lucan Electric Railway Company	0·25	250	200	14·3
Sutton and Howth Tramway	0·226	375	425	28·9

county up to and for some distance beyond Tallaght would thus be opened up, houses would be built adjacent to the tramway, and sufficient traffic developed to justify the electrification of the remainder of the line at a later date. A substation at Terenure would suffice for the electrical working of the line as far as Tallaght, and the whole cost of the scheme would not be serious.

It is impossible to conclude this paper without referring to the Central Ireland Power Company which obtained powers in the year 1908 for generating electricity on the Bog of Allen and distributing it to Dublin and the surrounding country. Although this company has not up to the present established a generating station it is not absolutely defunct. The steady advance in the price of coal, and the improvements which have been made in producers and gas-fired boilers, balance of the demand should be supplied from the bog stations. The results obtained at Chester where the water power is used on these lines are most encouraging, as the total cost per unit generated from the water-power plant over a period of 3½ years has only been 0·2353d. per unit, inclusive of interest and sinking fund and in spite of the fact that the power is seriously affected by the tide.

A high-pressure distribution system such as suggested would provide for electrification of the railways and would enable power to be sold at a cheap rate for agricultural purposes.

The use of electricity on farms has attracted attention in America and Canada both for ploughing and for the minor operations of threshing, cutting up foodstuffs, and providing light. Recent experiments show

that an expenditure of from 19 to 23 units per acre according to the depth are required for ploughing, the operation being carried out at the rate of about 2 acres per hour, and a charge of 1½d. per unit has been found sufficiently low to make ploughing by electricity economical compared with either petrol tractors or horses.

The successful production of power from the bogs depends on the drying of peat on a large scale and at a reasonable cost until the water present in the peat does not much exceed 50 per cent of the total weight, in which condition the peat is suitable for burning in producers for the production of power gas and the recovery of a large proportion of the nitrogen present in the form of ammonium sulphate.

The lower layers of most of the Irish bogs yield valuable fuel having a calorific value up to 10,000 therms per lb. of anhydrous peat and containing 18 to 20 per cent of moisture when well dried in the open air, or about 12 per cent when dried under cover. Such peat when packed close occupies about 1 cubic yard per 1,000 lb., which means that it requires just three times the space taken up by a quantity of good broken coal of the same calorific value. The storage of a sufficient quantity of this superior material under shelter, to act as a safeguard against the failure of the supply of ordinary peat during exceptionally wet seasons, would therefore appear to be practicable. In regard to the exhaustion of the bog areas, it may be taken that the average workable depth of the principal low-lying bogs is some 20 feet, which is equivalent to 2,000 tons of anhydrous peat per acre.

A station using gas-fired boilers and steam turbines of fairly large size might be expected to produce a continuous output of 1,700 kw. for each 100 tons of anhydrous peat consumed per 24 hours, and a station working on a load factor of 40 per cent might be expected to carry a maximum load of 3,000 kw. for each 100 tons of anhydrous peat consumed per 24 hours. For economical production actual stations should be of such a size as to consume some 300 tons of anhydrous peat per 24 hours, and such a station would exhaust the area of a bog having an average working depth of 20 feet at the rate of about 55 acres per annum. As many of the bogs have areas of over 5,000 acres and some exceed 10,000 acres in extent, it will be seen that these stations could be maintained for a large number of years.

In regard to the use of water power in conjunction with steam-driven generating stations, it is important to notice that the demand in winter time when the water power is at a maximum is greater than during the summer season. This is true not only for the evening lighting load but also for the average load from early morning (6 a.m.) until dusk; the latter load appears to be greater in Dublin in the ratio of 100 to 70, and in Pembroke and also in Rathmines in the ratio of 100 to 38, in winter as compared with summer. This may be ascribed partly to the demand for heating purposes, which only exists in cold weather, and partly to the greater industrial activity which prevails in winter.

The water power in Canada and in many parts of Europe is at its lowest during the winter season when the water is locked up in the form of snow and ice, and in such places it does not pay to develop water power much beyond the minimum flow because this condition obtains at the time of maximum demand. In Ireland it would pay to develop up to the full winter flow of the rivers in a combined system such as has been suggested.

The greater part of this paper was written nearly a year ago, and in the interval the linking up of power stations and the placing of the supply of electricity on a broader and more economical basis has become a burning question.

The urgent necessity of new legislation dealing with the matter of wayleaves for electric power lines has been clearly demonstrated, and it is the duty of our engineers to use all their influence to secure that Ireland shall not be excluded from the beneficial legislation dealing with this matter which cannot be long delayed.

In conclusion the author hopes that the suggestions made in this paper may give rise to a vigorous and useful discussion.

Discussion.

Mr. Harriss. Mr. G. M. Harriss: I notice that the author is in favour of the district being supplied from two large stations, principally, I think, on the grounds that the scrapping of so much machinery as would be involved by the shutting down of one of the existing stations would not be entertained, although, he states, the Pigeon House is a bad site, as we all agree it is. The author has, however, explained that his views were those of a year ago, and I think that if the paper were written now in the light of the attention that has been focused on the necessity for the cheapest possible methods of producing power, he would be better prepared to face the problem on broader lines. I am unable to follow the suggestions in favour of the tramway company undertaking the supply of power for the Hill of Howth Tramways and the Lucan Tramways and not supplying the townships of Rathmines and Pembroke, which are very much nearer and in both of which districts the tramway company has effects available for laying mains to the different distribution centres. Having regard to the advantages of the better site of the tramway power station, I see nothing to recommend an extension of the Pigeon House station. I do not think the author's suggestion to build a retaining wall from the Pigeon House to the Sandymount Tower would be justified for the purpose of affording facilities for laying mains. The demand for such mains would be very small indeed in that direction. The reclamation of the land, however, is an infinitely more important point, and on that account only the retaining wall might be feasible, though it is a problem in marine engineering of no little importance. The author mentions 60 kilowatts as sufficient to supply the probable demands in Dundrum and Foxrock. I am of opinion this is rather too low; I should expect a good deal more than this in those districts. The Mr. Ha

rriss. suggestion to have a tunnel under the River Liffey available for workmen and at the same time for carrying mains is a very good one; such a tunnel is very desirable if the scheme could be carried out. I cannot, however, see in what way the Pigeon House station would be better, or nearly as well, able to supply this district as the tramway company with their station so much closer. The author has referred to the desirability of running overhead mains outside the city. I quite agree with him in that and I also think there are a large number of suitable places inside the city where overhead mains could be run with advantage. I should like to emphasize how necessary it is that there should be one large central supply station suitably situated for obtaining a cheap supply of coal and an ample supply of good water for condensing purposes and with room for future extensions.

rte. Mr. A. E. Porte: The author does not mention in his paper such industrial concerns as Messrs. Guinness, Messrs. Jacobs, and other large firms having power stations of their own, which could take a supply from a large central station; how would a large station compete with a concern like Messrs. Guinness in offering to supply them with power at a lower cost than they are generating at? I know that their cost per kilowatt is very low. Considering the case of a flour mill, with 100 per cent load factor, running for 365 days in the year, could we offer them current at a lower figure than their present average cost, which is about 0·3 of a penny. I am glad to note that the author is in favour of a high-tension alternating-current system, my own experience of continuous current being that it is much more inclined to develop faults on a large system. In speaking of the use of gas for firing purposes, I see no reason why the Pigeon House sewage works should not be made use of by obtaining producer gas from the sludge. I estimate the available quantity of gas at 4 million cubic feet daily of a calorific value of about 130 therms. Mr. Harriss seems to scout the idea of building a marine wall from the Pigeon House to Sandymount. Personally I do not think the cost would be excessive, as I know of a somewhat similar case in which the cost was about £25,000. For outlying stations of small size, I am of opinion that the installation of Diesel engines would be more economical than transmission over a long distance; such plant could be moved to a more distant part of the district as the load developed, and the rest of the power demand could be supplied by overhead transmission lines.

Mr. G. F. Pilditch: I fear that a certain amount of opposition may still be looked for from public bodies, but I believe that the time has now arrived when such opposition will not be allowed to interfere with the carrying out of any scheme which, by saving coal, would be beneficial to the country. I notice from published returns that several undertakings in England which in 1914 were making a profit are now running at a considerable loss. These undertakings are linking up wherever possible, and I believe that this will result in a general reduction all round in the coal consumption and working costs, and possibly place these undertakings in a sound financial position again. The Rathmines undertaking has, like many others, been badly affected by the war, and in order to meet additional expenditure due to the increased cost of coal, etc., the charges for electrical energy were increased in 1916 and again in 1917. The first increase caused a corresponding economy on the part of consumers, and this, together with the effect of the Summer Time Act, resulted in a considerable reduction in the revenue as compared with the previous year, instead of an increase. Since there is a limit to economy, however, and as "daylight saving" has done its worst, I hope and believe that the further increase in the charges recently made will result in a corresponding increase in revenue. I am in favour of linking up in the Dublin area, provided that it can be done at not too great a capital cost. I believe that the result would be beneficial to all concerned and would result in a very considerable saving of coal; and any scheme that will save coal is of national importance and should be carried out without delay. Mr. Pilditch.

Mr. S. L. R. Price: I cannot think that any station engineer who had the real interest of his job at heart would object to any scheme which it had been conclusively proved would be for the benefit of his particular undertaking. The question to be settled, as it appears to me, is: Are all the stations to be merged into one large comprehensive central supply unit, or will one of the two existing larger stations, i.e. the municipality or the tramway company, undertake to supply in bulk as required, to the smaller undertakings? It is my belief that some scheme of co-operation such as this latter arrangement would work well for all concerned. Considering our own particular case the early morning load and part of the day supply could more efficiently be dealt with by the purchase of a bulk supply on suitable terms. Our own particular case is peculiar and would require special consideration, for our electricity generation is dependent on three distinct methods of power development, of which coal-fired boilers is the least important. Of the other two, namely, refuse-fired boilers and Diesel oil-engines, it must at once be agreed that the method is most economical in every sense of the word and probably goes farther to attain the Government's aims in the direction of coal economy than any other method. With regard to the Diesel engines, the fact that we are able to run on tar-oil obtained from the gas company just across the road must be agreed to be a highly economical arrangement, obviating, as it does, the using of coal at a time such as the present and using in its stead a local by-product of very much less general importance. I think the economical possibilities of a mixed arrangement such as we have must be at once admitted by all, for it is possible to run the steam sets continuously on their most economical loads and then to introduce the oil engines as required—without any stand-by loss—to cut away any peaks or to relieve the steam plant at heavy portions of the load. Now it is the stand-by losses which so sorely cripple small undertakings, and these being eliminated, the price at which current is purchased in bulk would have to be a very fairly low one before it could be said to be in any way attractive or advantageous. Mr. Price.

Mr. R. Tanham: Regarding the paragraph for a Tanham.

Mr. Tanham.

supply at liberal terms for factories, etc., centralization of plant with its resultant good load factor should provide for this; some people are now taking in town gas to generate their own electricity. The author's figures of 16 to 20 lb. of steam per unit for reciprocating sets of the sizes mentioned appear fair. A few years ago a combination of reciprocating engine and turbine was considered to be the best way of obtaining economy; this is now altered in many stations by the high-pressure turbine. Our results at Ringsend, working with reciprocating engine—turbine combination, come out at the lower figure mentioned by the author, and when working with reciprocating engines only, the highest figure or a little more is reached. With regard to the author's steam consumption figure for modern turbines of from 3,000 to 5,000 kilowatts, I think it right to mention that it is necessary to have high speed with modern steam conditions and high vacuum to get good results; that is, a speed of 3,000 r.p.m., a gauge pressure of 200 lb. per square inch, and 200 degrees F. superheat with low temperature and ample cooling water to get a vacuum of, say, 28½ inches with 30-inch barometer reading. The following figures from a paper recently read may be interesting: A 3,000 kw. turbine running at 1,500 r.p.m. working under the conditions I have just mentioned takes about 13·75 lb. of steam per kw.-hour, or about 6 per cent more than the same size set running at 3,000 r.p.m. under the same conditions. The machine of the latter speed costs about 27½ per cent less per kilowatt. A 5,000 kw. set running at 3,000 r.p.m. operating under the conditions just mentioned consumes 12·75 lb. per kw.-hour, or 2¾ per cent more than if designed to run at 1,500 r.p.m. Sets of 5,000 kw. capacity appear, so far as I am aware, to be the largest that are running at 3,000 r.p.m. Regarding capital already expended, the author refers to improvements in generation by using gas after distillation of coal. This appears to be gaining favour because we are at present wasting practically all the by-products of coal, and it is thought that what is now a commodity will be looked upon as the residual. A works operating in this manner is hardly likely to be started here, but consideration could be given to other methods of generating power. Plants using powdered coal, for instance, are now working; the use of this powdered or pulverized fuel appears to be a commercial proposition for large plants, and it is said that the cost of pulverized coal at 15s. per ton compares with fuel oil at 1½d. per gallon. The author points out that the tramway company generate three-phase current at a frequency of 25, which is especially suitable for rotary converters. I do not know whether this may be taken that a higher frequency than 25 is not especially suitable. Certainly there is no trouble in operating rotary converters on 25 periods, and although there are many systems working them at 50 or more periods there are reasons that will allow competition between the 50-period rotary converter and the motor converter; the latter machine is seldom used on 25 periods. Overhead three-phase high-tension transmission lines to Sutton and Lucan have been referred to as possible to work on each route outside the city boundary or even inside the city boundary. As far as the line to Sutton station for the Great Northern Railway is concerned, this could easily be done without going through hardly any part of the city, by running from Brunswick-street an aerial line along the railway direct to Sutton. Both the Sutton and Lucan systems would for many hours during the working day require no current at all owing to the half-hourly or hourly car service running, and I think that automatic substations would work very well in these places and do away with practically all running costs other than the cost of power.

Mr. Tanham

Mr. R. F. Fry: I am of the opinion that it will be a very long time before such outlying stations as my own (Greystones) are linked-up to a large central station, as it would scarcely be a paying proposition to run high-tension mains over such a long distance.

Mr. Fry

Mr. W. Tatlow (*in reply*): In answer to Mr. Harriss's remarks about the suggested bank from the Pigeon House station to Sandymount, it would be quite easy to carry an overhead line across the sands on steel towers with concrete bases, but such a line might be objected to as unsightly. Some years ago a Dutch syndicate proposed to purchase and reclaim these sands for the purpose of establishing a bulb farm, but the negotiations fell through. The reason why I proposed to limit the tramway power station to providing power for traction was that there was no competition with the Dublin Corporation in regard to traction, and the tramway company would have a reasonable prospect of getting their Parliamentary powers altered in this respect. Personally I should like to see the tramway company freed from all restrictions in regard to the sale of electric power.

Mr. Tat

In reply to Mr. Porte I do not think it would be possible to supply Messrs. Guinness more cheaply than they themselves can generate, as large quantities of heat are required for brewing operations and this heat is obtained from the exhaust steam of the engines. The supply of corn mills having load factors approaching 100 per cent might be possible if the generating station used waste gases from a coal-distillation process as pointed out in the paper, or if power were brought into Dublin from the bogs.

Mr. Price mentioned the good results which he was obtaining from Diesel engines burning tar-oil. Where Diesel engines are already installed I think they should be worked on the peak load, but the high cost of these engines is a very serious objection to them in the case of further extensions.

Mr. Tanham had drawn attention to the improved results which have been obtained by the use of higher speeds from steam turbines. With reference to this I should like to mention the remarkable results obtained from a Lunjstrom turbine of only 1,000 kw. capacity which has shown on test a consumption of only 12¾ lb. of steam per kilowatt-hour. The rotation of the two elements of this turbine in opposite directions is equivalent to doubling the running speed.

I think Mr. Fry might obtain a bulk supply for his lighting station at Greystones if the railway from Dublin to Greystones were electrified. I believe that the electrification of this line will be carried out before many years.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 56. FEBRUARY, 1918. No. 271.

THE "PROS AND CONS" OF THE METRIC SYSTEM.

By Llewelyn B. Atkinson, Member.

(*Paper received* 19 *November, and read before* The Institution, 13 *December*, 1917.)

Introductory.

For the past 30 years there has been a discussion proceeding as to whether Great Britain should adopt the Metric System of Weights and Measures. The discussion is still proceeding and whatever may have been its educative value, it does not seem as if the final answer is nearer than it was 30 years ago. As the Institution is proposing to take part in this discussion the author has been asked to contribute a short paper on the "pros and cons" of the question. This paper is an endeavour to define clearly the real issues that are the subject matter of such a discussion, without obscuring these by a large number of minor and unimportant considerations which are often brought into the discussion of the subject. The paper will further make some suggestions endeavouring to reconcile the conflicting views that are held, and to suggest the means whereby if it should be decided that the adoption of the metric system is desirable, it might be introduced with a minimum of confusion and opposition. The paper endeavours not to take a partisan view on one side or the other, though it will be well to state at the outset that the author is personally in favour of the eventual adoption of a *decimal* system of coinage, and of the *metric* system of weights and measures as the legal standard of weights and measures for the Empire. Having in the past had discussions with many authorities on this question, the author has frequently been surprised at the lack of precise and definite ideas in the minds even of those who are strongly advocating or opposing a change in the present systems current in this country, and he believes that it is largely this lack of precision which prevents a decision being reached. The lack of precision is partly due to a confusion between decimalization and metric measures, and partly as between the metric system and the absolute (C.G.S. or scientific) system, and partly due to want of knowledge of what are the legal standards in each system.

The Questions at Issue.

If we strip the points at issue free from all archæological, historical, and fanciful considerations, and bring it down to a question of what is the way of measuring the moneys and physical quantities with which we have to deal in ordinary life, or in scientific work, which is best adapted to the life and business of the country, we are reduced to something like the following :—

(1) *The question of the decimalization of moneys, weights and measures*, that is :—

(*a*) Is a system of moneys or weights or measures, in which the successive magnitudes are multiples of 10, better than a system in which other multiplying factors are used ?

(*b*) If so, is the metric system of weights and measures (which is a decimal system) the best system to adopt, and what monetary system should be adopted ?

(2) *The question of the actual magnitudes involved*, that is :—

Are the metre, the kilogram, and the litre, with their multiples and sub-multiples, better than the yard, the pound, and the gallon, with their multiples and sub-divisions, either absolutely, or because of their arithmetical relations ?

(3) *The question of policy.*

(*a*) Is it so desirable to have a universal world-wide system that even at the risk of not having the best system, we should adopt a system which would then become universal?

(*b*) If so, is it good business at this particular moment to adopt a system with which our enemies are more familiar than we are?

It would appear that if we can confine the discussion to such definite questions as are given above, which really cover the whole ground, it should be possible to arrive at a definite conclusion on which some action might be founded. Leaving the coinage question for the moment, it will be useful to commence by setting out the systems of weights and measures which are under discussion, as follows:—

The British System.
The Metric System.
The C.G.S. or Absolute System.

British System of Weights and Measures—Legal Standards.

Standard of length.—The yard. Being the distance between two lines measured at a temperature of 62° F. on a standard bar deposited at the Standards Office of the Board of Trade at Old Palace Yard, London.

Standard of weight.—The pound. Being the weight *in vacuo*, at London, of a standard cylinder of platinum deposited at the same place.

Standard of capacity.—The gallon. Being the volume of 10 lb. of distilled water at 62° F. weighed in air,* also at 62° F., the barometer being at 30 in. of mercury against brass weights.†

Metric System of Weights and Measures—Legal Standards.

Standard of length.—The metre. Being the distance measured at 0° C. between two lines on a standard bar deposited at the International Bureau of Weights and Measures at Sèvres, Paris.

Standard of mass.—The kilogram. Being the mass of a piece of platinum iridium deposited at the same place.

Standard of capacity.—The litre. Being the volume of a cube having for each dimension a length of 1/10th of the metre as above defined.

C.G.S. or Absolute System—Standards.‡

Standard of length.—The centimetre. Being 1/100th part of the metre as above defined.

Standard of mass.—The gramme. Being 1/1,000th part of the kilogram as above defined.

Standard of capacity.—1 cubic centimetre. Being 1/1,000th part of the standard of capacity as above defined.

It is desirable to call attention to the fact that in the British system there is strictly speaking no standard of *mass*. The standard which is legalized is a standard of *weight* or *pressure*, and as such can only apply relatively to a standard mass at the particular place specified, which is London. The *mass* which weighs one pound varies from point to point on the earth's surface, being one-half per cent greater at the equator than at the poles.

The three systems named above being defined as to their legal standards, it becomes necessary owing to the range of sizes which have to be measured, to have multiples or sub-multiples of these units.

It is customary in schools and works of reference in setting out tables showing the multiples and sub-multiples, to include a very large number of measures which relate only to specific trades or goods, and which are, in fact, never used except by a comparatively small number of people dealing in particular products. This is one of the primary causes of the confusion which exists as to the merits of British and other systems of weights and measures. This practice holds good especially in British tables, but also obtains in tables of metric measurements, where there are large numbers of multiples and sub-multiples which are set out and which have names given to them which are never met with in any practical work. In the case of the C.G.S. or Absolute System, no such tables as a rule exist, and it remains to consult books of reference to find out what are the multiples that are ordinarily being used, which are those expressed by a figure multiplied by a power of 10. The author therefore sets out below tables of multiples and sub-multiples of the units in these various systems, which really are the multiples with which trade, commerce, and scientific work are carried on.*

British Tables of Length, Area, Capacity, and Weight in General Use.

Measures of Length.

	General Purposes					Some Engineering and Special Purposes	
Fractions of 1 inch	$\frac{1}{64}$	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{1000}$	$\frac{1}{100}$

1 inch
12 in. = 1 foot
3 ft. = 1 yard†
1,760 yards = 1 mile

Land Surveying
100 links = 1 chain (22 yards)
10 chains = 1 furlong
8 furlongs = 1 mile

* Presumably dry air (author). † Density not stated (author).
‡ These standards are not directly legalized in any country, though some of the derived standards are.

* It is of interest to consider what are the order of maximum and minimum magnitudes in nature, so far as length and mass are concerned, with which it is likely that any system of measurement will have to deal. We may take as the smallest, for example, the diameter of 1 electron, this is an approximately 2×10^{-13} cm. At the other end of the scale we may take the distance from the sun to the farthest visible star, which is approximately 3×10^{21} cm. The mass of 1 electron is $0{\cdot}61 \times 10^{-27}$ grammes, whilst it has been estimated by Fournier D'Albe that the quantity of matter in the galaxy is of the order 10^{53} grammes.

† The Legal Standard.

Measures of Area.

General Purposes	Land Surveying
144 sq. in. = 1 sq. ft.	25 links squared = 1 sq. pole
9 sq. ft. = 1 sq. yard*	40 sq. poles = 1 rood
	4 roods = 1 acre
	or
	100 links squared = 1 sq. chain
	10 sq. chains = 1 acre

Measures of Volume.

Multiplier	General Purposes	Engineering Purposes
(2^2)	4 gills = 1 pint	1,728 cub. in. = 1 cub. ft
(2)	2 pints = 1 quart	27 cub. ft. = 1 cub. yd
(2^2)	4 quarts = 1 gallon *	
(2^3)	8 gallons = 1 bushel	
(2^3)	8 bushels = 1 quarter	

Measures of Weight.

(2^2)	4 oz. = $\frac{1}{4}$ lb.	for small quantities
(2^2)	$4\frac{1}{4}$ lb. = 1 lb.*	for small quantities
	1 stone of 14 lb. (the unit)	for large quantities
(2)	2 stones = 1 quarter	for large quantities
(2^2)	4 quarters = 1 cwt.	for large quantities
(2×10)	20 cwt = 1 ton	for large quantities

Connections between units:—

1 gallon = 10 lb. of water at 62° F.*
1 cub. ft. of water at max. density 4° C. = 1,000 oz. (998·2).
A cube of 5 links = 2,240 lb. of water at 32° F.†

Other British Units.

The unit of *force* and *pressure* are respectively the pound, and the pound per square inch.

The unit of *work* is the force of one pound acting through one foot (foot lb.).

The unit of *power* is one foot lb. per second.

Metric Tables of Length, Area, Capacity, and Mass in General Use.

Measures of Length.

Multiplier	
(10)	10 millimetres = 1 centimetre
(10^2)	100 centimetres = 1 metre
(10^3)	1,000 metres = 1 kilometre

Measures of Area.

(10^2)	100 sq. millimetres = 1 sq. centimetre
(10^4)	10,000 sq. centimetres = 1 sq. metre
(10^4)	10,000 sq. metres = 1 hectare

Measures of Volume.

(10^3)	1,000 cub. centimetres = 1 litre
(10^2)	100 litres = 1 hectolitre

Mass.

(10)	10 milligrammes = 1 centigramme
(10^2)	100 centigrammes = 1 gramme
(10^3)	1,000 grammes = 1 kilogram
(10^3)	1,000 kilograms = 1 tonne

* The Legal Standards.
† See "British Trade and the Metric System," by E. A. W. Phillips.

Connections between units:—

1 litre = 10 cm. cube = 1,000 cub. centimetres.
1 kilogram = mass of 1000·028 c.c. of water at 4° C.
So 1 kilogram = 1·000028 litres of water at 4° C.
1 litre * of water at 4° C. = 0·9999720 kilogram.

Other Metric Units.

The units of *force* and *pressure* are respectively *the weight* of a kilogram at Paris, and the weight of a kilogram at Paris per square centimetre (or per square metre), or generally for steam and gases in engineering *the atmosphere* is taken as the unit of pressure = 1·033 kilograms per sq. cm. (approx.).

The unit of *work* is the weight of a kilogram (at Paris) acting through a distance of one metre (one kilogram-metre).

The unit of *power* is the kilogram-metre per second.

The C.G.S. System of Units.

Used for scientific purposes.

Unit of length.—1 centimetre.
Unit of area.—1 square centimetre.
Unit of volume.—1 cubic centimetre.
Unit of mass.—1 gramme.

Connection between units:—

1 gramme is the mass of 1·000028 cub. cm. of water at 4° C.

Other C.G.S. Units.

The unit of *force* is the dyne and is the force which acting for one second on a mass of one gramme will give it a velocity of one centimetre per second = 1/980·6 (weight of a gramme at Paris).

The unit of *pressure* is the Barad or Bar, being one dyne per square centimetre (1 megabar = 10^6 C.G.S. units).

The unit of *work* is the erg = 1 dyne × 1 cm. = 1/98,060 kilogram-metre (at Paris).

The unit of *power* is the erg per second.

Absolute electrical units are based on these, but the electrical units in practical use, viz. the *ohm*, *volt*, *ampere*, etc.,†-and multiples of these, are used as in the following table:—

Electrical Units.

Resistance.

10^3	C.G.S. units = 1 microhm
10^9	,, ,, = 1 ohm
10^{15}	,, ,, = 1 megohm

Electric Current.

10^{-4}	C.G.S units = 1 milliampere
10^{-1}	,, ,, = 1 ampere

* If the equivalence of mass is measured by weighing against brass weights in air, the water and air being at 4° C., 1 litre = 0·9987 kilogram.
If the equivalence of mass is measured by weighing against brass weights in air, the water and air at 62° F., 1 litre = 0·9976 kilogram.
† The practical electrical units are a self-contained series of absolute units in which the basis units are Length 10^9 centimetres, Mass 1 gramme, Time 1 second.

Self-induction.

10^3 C.G.S. units = 1 millihenry
10^9 ,, ,, = 1 henry

Electromotive Force.

10^2 C.G.S. units = 1 microvolt
10^8 ,, ,, = 1 volt
10^{11} ,, ,, = 1 kilovolt

Capacity.

10^{-15} C.G.S. units = 1 microfarad
10^{-9} ,, ,, = 1 farad

Electric Power.

10^7 C.G.S. units = 1 watt
10^{10} ,, ,, = 1 kilowatt

As has already been indicated, there are in use by special trades British measures which are related to the British tables, but they are not in general use and may be regarded as statements of certain practical facts. A few examples of these may be given.

In *shipping*, for instance 40 cubic ft. = 1 ton. What does it mean? It means that for bulky goods they will be considered as if they were of the average specific gravity of a ship's cargo which for this purpose is taken at 0·896 or 56 lb. per cubic foot.

Corn measures.—Cereals of various kinds are actually sold by weight, but because they are usually packed in a sack which holds a certain volume and because different sizes of sacks are not used for different kinds of cereals, they are referred to in bushels. The weight of a bushel of each cereal is different from that of every other cereal. This is a fact that no system of weights and measures can overcome.

Meat.—Attention is frequently called to the fact that whereas the *standard stone* is one of 14 lb., meat is sold by a *Smithfield stone* of 8 lb. The explanation is perfectly simple, viz. that when an animal which weighs a given number of stones of 14 lb. has been killed and the blood and insides have been removed, the killed meat remaining will average 8/14ths of the original animal weight, and consequently when one buys an 8 lb. stone of meat, one is really buying a 14-lb. stone of animal, and the use of these two weights saves making a multiplication by 0·57 in every transaction which a butcher enters upon.

In the same category may be included all special Beer and Wine measures, Hay and Straw measures, etc. They arise from certain current sizes of packages or weights that can be handled by a man or by a horse.

We find many such examples, and nearly every trade has, apart from the standard legal measures of the country, certain measures which suit its own business, but strictly these have nothing to do with British standards.

The arguments so often used as to the amount of time spent in learning the British tables of weights and measures are answerable by the statement, that it is due to the fact that those in charge of education are so out of touch with real facts, that they do not know what weights and measures are used, and consequently maintain tables of weights and measures which have no practical existence.

No one ever uses a barley-corn, or a drachm (avoirdupois). No one except a London gas company to sell coke, ever uses a chaldron. No one except Jules Verne uses a league, and his league was 3,666 yards, not 3 miles as shown in English table books. Again the schoolmaster mixes up in one table, yard measures of length and area, with chain measures for the same quantities. They are two distinct systems, and the chain system though only used by land surveyors is a complete system, proceeding by multiples of 10, and like the metric system has a direct volume-weight connection with the length.

The questions which were set out early in this paper may now be dealt with.

The Question of Decimalization.

If we examine the table of weights and measures above given in the various systems, we shall realize that so far as the actual learning of these tables or the number of names or figures to be mastered, there is little difference between them. The underlying and essential difference being that the British system of length up to the yard, and of weights and measures proceed by multiples of 2, the metric and C.G.S. system by multiples of 10.* This point is vital and fundamental. The arguments put forward by scientific people and merchants and traders, so far as they relate to the arithmetical side of the question, pivot on this difference.

Why do these differences present advantages to different groups of individuals? The author thinks the answer is this. Wherever it is required to do a calculation by a calculating machine, or by a slide rule, or table of logarithms, or any of this class of aid to rapid calculation, or to perform additions, there is no question but that measures which proceed by multiples of 10, following our decimal system of arithmetic, are superior to any others. There are, in fact, no machines or calculating tables (other than ready reckoners) which enable calculations to be performed unless the quantities are first expressed in decimal notation. On the other hand, we must recollect that at least 90 per cent of the people of any country in the ordinary operations of their business and life do not use any of these aids to calculation, and they perform their calculations by mental arithmetic or by ready reckoners, and it is because it is simpler to have a variety of units connected together by such short intervals as 2 and 4 and other multiples of 2, enabling mental arithmetic to be performed very easily, that a system of weights and measures founded on short stages with these simple multipliers between them, are with such difficulty displaced by a system in which much more extended multiplications are necessary. In other words, to arrive at a decision as to whether

* Considerable stress has been laid by many writers (including Herbert Spencer) on the advantage of 12, a number divisible by 2, 3, 4, and 6, as a factor for multiples and sub-multiples, and it has been suggested that by use of a duo-decimal arithmetic this number could be used as a factor. It does not appear, however, that there is any real need for the 3 factor. In all the ordinary tables we find 12 only twice, viz. in the inch-foot ratio, and in the penny-shilling ratio. This appears effectually to dispose of the argument that 12 is a ratio of such importance that we should alter our arithmetic base.

a decimal system or a system like the British system is the best to use, we have to decide whether it is more important to cater for a large mass of people of moderate ability who work by mental arithmetic, or whether it is better to cater for those of a higher scale of ability and able to use aids to calculation.* And on this point it is absolutely essential to realize that very few individuals in Great Britain are able to carry on multiplications in their head beyond 12 times 12, and probably not half of the population can do as much, and further that not 10 per cent of the population are able either mentally or on paper to multiply together or divide 2 numbers containing decimal points, and to place the decimal point correctly in the answer arrived at.

Question of the Actual Magnitudes Involved.

Some words may now be said on the actual merits for general and engineering purposes of the units existing in the various systems. So far as ordinary trading and domestic purposes are concerned, there is no doubt that the pound and the half-kilo weight are the weights best suited for the mass of the population, the kilogram being too heavy for a general standard. For wholesale purposes the ton, or 1,000 kilograms are units which are of a right magnitude, whilst the weight of about 1 cwt. or 112 lb. (say 50 kilos) is another weight which is more useful than 100 kilos because it happens to be about the maximum weight that a man can conveniently handle.

For measures of length there is obviously nothing to choose between a metre and a yard, whilst the foot is an exceedingly useful dimension. For general purposes probably a centimetre is more useful, needing less sub-dividing, than the inch, but on the other hand the 1/16 inch, which is the smallest measure used in general work, is better than 1 millimetre, which is too small. In engineering the 1/100 and 1 1,000 of an inch are generally conceded to be more useful than the millimetre and the tenth of a millimetre. Thus so far as the actual magnitudes are concerned the balance of advantage seems to lie with the British standards of length.

As to measures of volume, there is not a great deal to choose, the $\frac{1}{2}$ pint which is a common measure is not far from the $\frac{1}{4}$ litre. One gallon and five litres being of the same order of magnitude are both readily expressible. As for the relations between the units of weight, length, and volume, in both systems the unit of volume is (approximately only) the volume of a definite weight of water, whilst the metric system presents the advantage of having the unit of volume also a direct multiple of the unit of length. This latter advantage, however, only appeals to engineers and scientific people, because ordinary people do not know how to perform calculations based on specific gravity, whilst for engineers and scientific people who must use tables, the use of a constant multiplier, or tables of weight per cubic inch or per gallon, instead of tables of specific gravity, is not a serious disadvantage.

On the questions therefore of absolute magnitude there seems to be no strong reason for advocating or for opposing a change in the standards.

In many discussions on the merits of the metric system it is argued that scientific measurements are all stated in metric units and that scientific men and engineers at least should be in favour of the adoption of the metric system, but this is only an approximate truth. Scientific results are stated in the C.G.S. system and apart from the fact that the centimetre is 100th part of the standard unit of length and that the gramme is 1,000th part of the unit of mass in the metric system, there is a fundamental difference in the method of measuring force or pressure, viz. that in the metric system this is expressed as the weight of a kilogram, that is to say, the force with which 1 kilogram (the standard mass) is attracted by the earth when at the earth's surface at Paris, whereas the unit of force in the C.G.S. system is the dyne, which is the force which acting on a mass of 1 gramme for one second gives a velocity of one centimetre per second. The consequence is that all units in the C.G.S. system, other than units depending on length and volume, have involved in them a multiplier which prevents their being directly translatable into metric units, and hence in any case scientific measurements and calculations must be stated and carried out in absolute units, and it is no more difficult to translate to the British pound system with a table of constants at one's side, than it is to translate to the metric system by using a similar table. The only advantage that lies with the use of the metric system is that standard metric measuring apparatus and standard weights may be used in work being carried out in the C.G.S. system.

The Question of Policy.

The point has now been reached where the question of policy may be considered. Is it desirable that a universal system of weights and measures should be adopted by all nations? It is conceded by all parties that this is in itself desirable; and the only question is whether the British system is better, so that an effort should be made to introduce that system universally, or whether it is so much better that it is well to keep it in the British Empire and America, even with the disadvantage involved in a non-universal system. And here it is that the answer depends on who has to give the answer. The vast bulk of the people of a country are never consciously affected by the weights and measures of another country; it is the merchants and engineers who are directly affected. Hence although a bad or difficult system of measures may hamper our foreign trade, as the bulk of people cannot appreciate

* If one may credit the statement below given by a firm manufacturing calculating machines which work decimally, the saving in time by the use of a decimal system of coinage and weights and measures does not appear to be very important.

Table of times taken to carry out calculations by a calculating machine:—

	£	s.	d.	
23 tons 7 cwt. 2 qr. 7 lb. at £2 6s. 8d. per ton	= 54	11	2¼	8 secs.
1033 yd. at 12s. 3½d. per yard	= 110	1	6	6 secs.
4,213 pieces at 2s. 3½d. per dozen	= 40	11	10½	11 secs.
Shipping.—348 ft. 6 in. at 53s. per 40 ft. + 10%	= 20	7	1½	9 secs.
Wages.—62½ hr. + 10% bonus base 58 hr. at 48s.	= 2	16	10½	7 secs.
Exchange.—Francs 22,650·75 at rate 27·78½	= 815	4	3½	5 secs.

the difficulty there is no general feeling of desire for a change, which is entirely confined to those with an international outlook.* But as the bulk of the population are not in a position to gauge the effect on our trade, it would be sound for those who are, to obtain the change by compulsory means if the case is absolutely clear. And this brings us to the further question which the events of the last three years forces to the front. Our trade rivals in the Central Powers already use the metric system; shall we as the war draws towards its end choose that moment to make a change that must cause some confusion and loss of energy, and which will have minimized the difficulty for our present enemies of penetrating and exploiting our own markets. Rather it would appear that whilst all men's minds are in the mood for great changes, some steps should perhaps be taken to remove the disadvantages for international trade under which we suffer, whilst retaining the advantage to the general body of the people of our own system.

Each of the questions stated at the beginning of this paper has now been discussed, and the points may be summarized so as to crystallize the issues.

1. (*a*) The question of a decimal system as against a system on the base of two, depends at present on whether we are to consider the convenience of a large number of persons doing mental arithmetic, or a smaller number calculating by other methods.
2. and 1. (*b*) On the question of the actual magnitudes involved, there seems no strong reason for or against the British or metric system, and if a decimal system is to be adopted it would seem most reasonable to adopt the one already understood by a large number, rather than construct a wholly new one.
3. (*c*) The question of policy seems to come to this, that it is common ground broadly that a universal system has great advantages, but those who favour the British system do not think the advantage of a universal system is a set off for the disadvantage of abandoning the British system. There is a widespread feeling for the reasons stated in the paper that the moment is inopportune for adopting the metric system.

Decimal Coinage.

The question of a decimal coinage is on a different footing from the question of a decimal system of weights and measures or as to the question of the metric or other universal system of weights and measures.

If every country in the world adopted similar gold coins and divided them similarly, equivalence of value would not have been reached, because so long as the basis of trade is a material substance like gold, the value in one place, of the standard of value at another place, will vary in a manner depending on the cost and security of transport between the two places. Hence a single international gold money standard is of no use.

The question of decimalizing the currency of any given country is therefore largely one of the convenience of the particular country only. The arguments in favour of a system of advances of the units by small steps (being multiples of two), as occur in the British weights, do not appear ever to have had the same force as in the case of measures of weight and capacity and the author thinks for this reason. The price of an article is generally quoted at per the unit of which a small number will be wanted. Thus prices of coal are quoted per ton, prices of butter per lb., prices of meat per lb. or per Smithfield stone, because these are the amounts which a buyer will require, and so the price being quoted in £, or shillings, or pence, the multiplication is a small one, and the result is usually in the same units as the price. The result is that the principal discussion as to decimalizing the British coinage really hinges on whether 12 as the base of the small denomination has great advantages over 10. There seems much less opposition to making the monetary base coincide with the arithmetic base, than is the case with weights and measures.

Considerations Affecting the Procedure to be Adopted if it should be Decided to Adopt Decimal Coinage and Metric Measurements in the United Kingdom.

The agitation and driving force favouring the change from our present systems of moneys and measures to a decimalized coinage and the metric system has centred upon the Decimal Association, and they have on several occasions, over a considerable period of years, endeavoured to obtain Parliamentary sanction to compulsory adoption of these systems, the experience of the 20 years since the use of the metric system became legal but not compulsory, having shown clearly that it will not be adopted unless under compulsion.

The author has, through the kindness of the Decimal Association, been able to study a list of their members and supporters, and it is a fair conclusion to state that substantially they consist of merchants, manufacturers doing a foreign trade, and to a much smaller degree engineering firms. Representatives of our two largest industries, viz. agriculture and the cotton trade, are almost entirely absent. This bears out what has previously been pointed out, that the movers for the change are those experiencing the advantage of a universal system for trading.

It would appear as if there would not be a great difficulty from a popular point of view at the present moment in decimalizing the coinage, and as is well known, a committee of bankers has recently considered this matter and has issued a report favourable to doing

* In order that there may be an appreciation of the number of persons and transactions affected by home and foreign trade the following may be noted. In the Final Report of the Census of Production (1907) a computation is given showing that the value of goods produced and consumed in the United Kingdom was (approximately) 1,385 million pounds (per annum). The value of goods produced in the United Kingdom and exported was 364 million pounds (per annum). The goods consumed in the United Kingdom being mostly distributed retail may certainly be taken to involve two transactions for each transaction involved in a similar value of export business. It therefore follows, that as far as the International question is involved, any change would be made on account of one-seventh of our total transactions, and of these probably one-half only relate to trade with metric countries.

so, the pound sterling being chosen as the standard of value, to be divided into one thousand parts. The Decimal Association which at an earlier stage favoured a unit of smaller denomination (a florin or a dollar) has, it appears from a recently issued circular, fallen in with the bankers' suggestion, probably not because they think it is the best, but because they think it is practicable to carry through a change which has the support of banking circles, which it would be impossible to carry through if they were opposing it. But the Association themselves apparently have misgivings as to the effect in ordinary commerce, as distinguished from book-keeping, which will arise from a system that will involve stating most prices as a decimal of a pound, or alternatively stating them as multiples of so small a unit as 1 1,000th of a pound. In the retail business of the country probably the majority of prices range between a few pence and a number of shillings less than one pound, and it is almost certain that they will be priced or stated in denominations much less than the pound itself. Let us suppose an article is valued at 7s. 6d. in our present values—this figure is 0·375 of £1 and it cannot be imagined that a shopkeeper will price the article in his window as 0·375 £—he is almost certain to price it as 3·75 florins, and this will inevitably involve a confusion and mistakes in accounts, because in entering up the bills, unless the whole of the books are kept in florins, there will be a doubt as to whether this item ought to be entered as 0·375 £ or as 3·75 Fl.

The Decimal Association has proposed to get over this difficulty by ruling the books as at present in three columns and apparently not using decimal points at all; in which case, in the instance quoted, the 3 would fall in its normal position in the second column, which would never contain more than one figure, whereas the last column would contain the final two figures. But if this proposal is to be adopted it appears to do away with the whole idea involved in decimalizing our currency and weights and measures. The system of setting out the value should be one which includes a decimal point so that it can be immediately operated upon by ordinary decimal arithmetic. But the proposal is for a system which involves putting in a decimal point that does not exist in the statement, which decimal point will frequently be inserted in the wrong place. The whole educative value of a decimalized coinage as leading to the adoption of other decimalized systems of measurement will have been lost.

The author feels no doubt that a great mistake is being made. He quite understands all the arguments referring to the prestige of the pound sterling in finance and banking, but this argument really relates to the fact that the pound sterling is a piece of gold and that, at least up to the time of war, all payments on London specified in pounds sterling were actually payable in these pieces of gold. From this point of view it would make not the slightest difference if it were understood that all payments of or over 10 florins were payable in 10 florins gold pieces called a £ sterling, and the adoption of the florin would have allowed the adoption of a simple decimal system of coinage easily understood, and having an educative value for future changes.

Whilst it would be very difficult at the present moment to obtain a sufficient popular support for a compulsory change of weights and measures to the metric system, very largely because the general population are not sufficiently educated in arithmetic to enable them to carry out by decimal arithmetic the mental calculations required in their daily business, the real difficulty so far as export and merchant business are concerned would be met by altering the standard of weight (or mass) to a pound which was equal to the mass of one half kilo.*

Let us look what this would mean. This new lb. would be 10 per cent heavier than the present lb. A ton of 2,000 such lb. would be equal to 2,204 of our present lb., or only about $1\frac{1}{2}$ per cent different from our present ton. A cwt. composed of 100 such lb. would also only differ by $1\frac{1}{2}$ per cent from our present cwt.

The Table of Weight would then be

	1 oz.	=1·102 old oz.	=31·3 grammes
16 oz.	=1 lb.	=1·102 old lb.	$=\frac{1}{2}$ kilo
$12\frac{1}{2}$ lb.	=1 stone	=0·98 old stone	$=6\frac{1}{4}$ kilos
2 stones	=1 quarter	=0·98 old quarter	$=12\frac{1}{2}$ kilos
4 quarters	=1 cwt.	=0·98 old cwt.	=50 kilos
20 cwt.	=1 ton	=0·98 old ton	=1,000 kilos

And eventually whilst the ton and cwt. and 2 lb. or kilo would remain, the rest would be dropped.

If the gallon as the measure of capacity were maintained at 10 lb. of water as it is at present stated, but restated at 4° C., it would be 5 litres capacity, and we should be in the position that without upsetting for the moment any of the arithmetic of our measures of weight and capacity, we should have obtained the multiples of the kilogram and litre which in the meantime would enable foreign transactions (for the most part wholesale) with metric countries to be conducted with a minimum of calculation, whilst the ground would have been prepared and the physical weights and measures would exist only requiring a change in name at a later stage.†

It is perfectly true that the question of the British measure of length would still remain outstanding.

The measure of capacity would not be derived by a simple measurement from the measure of length, but this point is, and always has been, more imaginary than real. If calculations have to be carried to a high degree of accuracy, it is not sufficient to ascertain the weight of an article to multiply the volume by the specific gravity. Corrections which must involve the

* Since this paper was written the author has had his attention called to the fact that this proposal has already been made in a pamphlet published in 1917 by Mr. Allen Granger ("Our Weights and Measures," Messrs. Eyre and Spottiswoode) in which the proposal is worked out in greater detail than is possible in this paper.

† The pound and the gallon have already had several changes: hence even historically there is no objection to another.

Before the year 1496 the pound was	7,200	grains.
In 1496 it became	7,680	,,
In 1824 ,,	7,000	,,

Before 1824 there were three separate gallons for corn, wine, and oil, of which the old wine gallon, 231 cub. inches, is still the standard in America.

In 1824 the gallon became legally	277·274	cub. inches.
In 1890 ,, ,,	277·463	,,

use of some form of notes or tables have to be applied, and it would be very little more trouble to use tables showing the weight per unit of volume of different substances than to apply a table of specific gravities corrected by a table as referred to.

It appears to the author therefore to be reasonable to suggest the following as a practicable and possible programme.

(1) Legalize and enforce decimalized currency.
(2) Obtain an alteration in the standard pound and gallon, making them in fact direct multiples of the kilogram and litre.
(3) Start an educational campaign based on improving the general standard of education so that a complete decimalized system could be brought into force and made compulsory, because it could be used by the people who have to use it.*
(4) And subsequently put in force compulsorily the metric system of weights and measures of capacity by merely changing the names and abolishing the multiples based on the factor 2.
(5) Finally put in force compulsorily the metric system of lengths, which will by that time have become largely used.

* To this end it is absolutely necessary that children should remain at school beyond the present age of 13. As long as they are allowed to leave the schools at the age of 13, they will never attain a standard of education or mental capacity where they can make use of general decimalized arithmetic. Further, the teaching of all tables of weights and measures, except those set out in this paper, should be abandoned and the metric system should be really taught. It is nominally included in the education code, but the children who leave at 13 have, as a very thorough teacher, the head master of a County school, recently said in reply to a question of mine, "only a smattering of the metric system."

It may not be inopportune to point out to the Decimal Association that the first of these in itself is a great work and will require much preparation before a Bill has any chance of being accepted by Parliament. A few points may be indicated.

There are hundreds of legal enactments which fix the price of tolls, railway rates, dock dues, charges for water, for gas, for electricity, for cabs, trains, buses, for stamps and fees, for sales of goods, forms, etc. Each of these has to be hunted up and scheduled; for each of these a proposal has to be made, and if possible agreed before the House of Commons is reached, as to who is to bear the cost of the change when the penny or the 1/240th of a pound becomes either four mills (1/250£) or 5 mills (1/200£). It may seem a trifling matter but it has to be settled.

As the same process will have to be gone through again if the metric measures of weight, volume, and length come into force, it certainly would be desirable at least to make the change in the lb. and gallon herein suggested, at the same time as the coinage is decimalized, because in certain cases it would ease the bargaining, and this would be some reason for adopting earlier the metre instead of the yard. At the same time some concrete proposals should be studied and discussed with the textile industries. Perhaps no industry involves such a mass of data and calculations in which the measurements of weight and length are so constantly involved, and the opposition of our largest manufacturing trade must be met in advance by indicating how the change can in practice be effected. The author believes that the programme he outlines is a practicable programme and one which might be realized in ten years if the educational problem were earnestly taken in hand.

A CASE FOR THE ADOPTION OF THE METRIC SYSTEM (AND DECIMAL COINAGE) BY GREAT BRITAIN.

By A. J. Stubbs, Member.

(*Paper first received* 26 *October*, 1917, *and in final form* 12 *January*, 1918; *and read before* The Institution, 13 *December*, 1917.)

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I. The Metric System.

(*a*) *Origin of the system.*—In view of some of the stock hypercriticisms that are produced against the metric system it may be well to clear the issue by a few preliminary notes in an attempt to distinguish between what the system *was* and what it *is*.

The idea really originated with our own James Watt, who, in a letter to a friend in 1783, suggested the introduction of an international system of weights and measures. Rather less than 120 years ago the French, who had previously formed an International Committee upon the subject, developed this idea into a very complete system—the more thorough because the Revolutionists were quite prepared to break away from everything pre-existing. They were even prepared entirely to disregard the original idea of internationalism. In such circumstances they proposed a 10-day week, a 10-hour day, a 100-minute hour, and a 100-second minute. In like manner they would divide the right angle into 100 degrees. As a practical matter these extreme proposals are of no value; and now only militant anti-decimalists ever suggest the idea of decimalization of time. That will become practical politics when we have induced the earth to revolve on its own axis exactly 100 (or 1,000) times while it goes once round the sun; when the moon agrees to go once round the earth during 10 (or 100) diurnal revolutions of the earth; when the inclination of the earth to its orbit has been corrected to an angle of 25/100 instead of its present $23\frac{1}{2}/90$ of a right angle; and when various other physical phenomena have adjusted themselves to a due relationship to the number of toes on a man's feet. In the meantime practical people will not favour the pressing of a theory beyond the limits of measurable benefit. Hence the metric system as it is, is simpler and more practical than the metric system as originally proposed. A hundred years of other people's experience naturally enables us to start with a clear idea of the working requirements.

(*b*) *Basis of the system.*—The whole system is based upon the *metre*—the measure. This title is given to the unit of *length*. It was intended that the length adopted should be one ten-millionth part of a quadrant of the earth's circumference—the quadrant was to be 100 degrees, the degree 100 minutes, the minute 100 seconds, and the *metre* was to be one-tenth of a second of arc. It really matters not at all that the scientists of those days bungled the calculation, because now the metre is the distance between two marks on a certain rod of platinum inserted in a concrete block in Paris, and on certain copies of this which have been distributed over the world.

The unit of weight — the kilogram — is derived theoretically from the metre as being the weight of one cubic decimetre of pure water at its maximum density. In practice the kilogram is represented physically by a certain piece of platinum which is accepted as one kilogram when weighed at a certain temperature under a certain barometric pressure.

The unit of capacity is the *litre*, which is the content of one cubic decimetre.

The primary units adopted are the metre, the gramme, and the litre. Sub and multiple units are derived by ratios of 10—the sub-units being designated by uniform

Latin and the multiple units by uniform Greek prefixes. The prefixes and the values defined in relation to the units are

milli	centi	deci		deka	hecto	kilo
$\frac{1}{1000}$	$\frac{1}{100}$	$\frac{1}{10}$	unit	10	100	1,000

In practice, quantities are expressed in one unit. For example we do not write

3 kg., 1 hg., 2 dag., 3 grm.,

but 3·123 kg.
or 3,123 grm.
or even 312,300 cg.

Also, in retail transactions it is often convenient to revert to fractions; and we should buy $1\frac{1}{2}$ kilos or $\frac{1}{4}$ kilo just as we do in pounds, except that as a kilo is larger than a pound we might more often take a fraction.

(*c*) *Comparison with English weights and measures.*— In the attached table I have set out in simple form our principal tables of length, weight, capacity, and square measure. It will be seen that for 26 items there are 17 different ratios, 2, 3, 4, $4\frac{1}{2}$, $5\frac{1}{2}$, 8, 9, 10, 12, 16, 20, 27 11/32, 28, $30\frac{1}{4}$, 40, 144, 1,000, whereas under the metric system the only ratio is 10—that of the ordinary notation.

Length.

English.	Metric.
mil × 1,000 =	millimetre (mm.) × 10 =
inch × 12 =	centimetre (cm.) × 10 =
foot × 3 =	decimetre (dm.) × 10 =
yard × $5\frac{1}{2}$ =	METRE (m.) × 10 =
rod, pole, or perch × 4 =	dekametre (dam.) × 10 =
chain × 10 =	hectometre (hm.) × 10 =
furlong × 8 =	KILOMETRE = 1,000 metres.
mile × 3 =	
league = 5,280 yards.	

Weight.

English.	Metric.
grain × 27 $\frac{11}{32}$ =	milligramme (mg.) × 10 =
dram × 16 =	centigramme (cg.) × 10 =
oz. × 16 =	decigramme (dg.) × 10 =
lb. × 28 =	GRAMME (grm.) × 10 =
qr. × 4 =	dekagramme (dag.) × 10 =
cwt. × 20 =	hectogramme (hg.) × 10 =
ton = 2,240 lb.	KILOGRAM (kg.) × 1,000 =
	TONNE.

Capacity.

English.	Metric
gill × 4 =	millilitre (ml.) × 10 =
pint × 2 =	centilitre (cl.) × 10 =
quart × 4 =	decilitre (dl.) × 10 =
gallon × 2 =	LITRE (lit.) × 10 =
peck × 4 =	dekalitre (dal.) × 10 =
bushel × 8 =	hectolitre (hl.) × 10 =
quarter × $4\frac{1}{2}$ = chaldron.	KILOLITRE (kl.) = 1,000 litres.

Area.

English.	Metric.
sq. inch × 12^2 =	sq. metre (sq. m.) × 10^2 =
sq. foot × 3^2 =	ARE (a.) × 10^2 =
sq. yard × $5\frac{1}{2}^2$ =	hectare (ha.) × 10^2 =
sq. rod or sq. perch × 40 =	SQ. KILOMETRE (sq. km.).
rood × 2^2 =	
acre = 4,840 sq. yards = $69{\cdot}58^2$.	

But the multiplicity of ratios is not the only objection to the chaos which we call our system.

Amongst the weights left out of my tables is the "stone." If one buys a "stone" of meat one gets 8 lb.; if one buys a "stone" of potatoes one gets 14 lb.

An attempt to decimalize the English weights has been made in the United States; so that, although when one buys a hundredweight of potatoes in England one gets 112 lb., the same order in America will bring only 100 lb.

In the weights we have the natural ratio of 4 "quarters" to the next higher unit (the cwt.), but in measures of capacity $4\frac{1}{2}$ quarters go to make the next unit—the chaldron.

Perhaps the most astounding condition in a community under the control of Weights and Measures Acts is that which obtains in regard to bartering in corn.

Corn is sold by weight, but reckoned in bushels. The standard weights of a bushel for various kinds of grain are:—

38, 39, 40, 50, 52, $52\frac{1}{2}$, 60, 62 lb.

but it is said that there are about 200 sizes of bushel in use.

Amongst other anomalies may be mentioned that while the lb. troy is less than the lb. avoirdupois, the oz. troy is greater than the oz. avoirdupois. This anomaly, however, has recently been abolished by the expedient of making the ounce the only troy weight unit. The ounce troy weighs 480 grains, but ounces and decimals are now the only legal standard. This reform has therefore practically swept away the only vestige of connection between troy and avoirdupois weights.

One other example of the system of chaos may be taken from our land measure. If one wants to set out a square of exactly one acre one can do so by making the side of the square the convenient length of rather less than 69·58 yards. Of course in the metric measures the length of the side of a square hectare is a hectometre and of a square kilometre is a kilometre, just as with us the length of side of a square yard is a yard.

II. ALTERNATIVE SYSTEMS.

Those who object to the adoption of the metric system often refer to alternatives. They admit the need of a change from the British weights and measures, but they say we can do better than adopt the metric system.

Now, I submit that there are only two possible courses open to the British people in this 20th century.

We can retain the British tables or we can adopt the metric tables. To talk about a duodecimal system, for instance, is only to waste words. Its introduction by universal agreement would create chaos, its introduction by a single nation could only be undertaken by a nation of madmen. If the human race had been gifted with five fingers and a thumb on each hand we should doubtless have had a duodecimal system of notation; but the basis of our notation for all time is our 10 digits, and duodecimal measures worked by a decimal notation have not the remotest chance of securing the adhesion of mankind. Neither is there a possibility of persuading non-users of the British measures to take up such a burden as adopting them, even though their trade may be largely with English-speaking nations and even though we "decimalize" some of the tables.

It is admitted on all hands that reform is necessary and pressing; I submit that the only practical way of mending our present system is to end it—so long as bushels may be used those 200 different measures will survive. I submit too that for practical purposes the only possible efficient substitute is the metric system.

III. Advantages of the Metric System.

(*a*) *Scientific basis.*—The benefit of the metric system being on a scientific basis is likely in itself to appeal to electrical engineers, who know the extreme advantage accruing from such a condition in connection with their own special units.

By universal consent all relations of weight are based upon the weight of a unit mass of pure water at its maximum density. Thus, for example, the specific gravity of water is taken as unity and all other materials are related to it by reference to the weight of equal mass. As a cubic foot of water weighs 62·288 lb. the weight of a cubic foot of any other material may be ascertained by multiplying its known specific gravity by 62·288 lb. Under the metric system as 1 cubic decimetre of pure water weighs 1 kilogram the weight in kilograms of any other material is represented by its specific gravity without calculation.

So with other ratios of everyday use:—

1 lb. per square inch pressure (of water) is given by a head of 2·31 ft., while
1 kilogram per square decimetre pressure is given by a head of 1 decimetre.
1 cubic yard of water weighs 15 cwt. 0 qr. 1·776 lb., but
1 cubic metre of water weighs 1 tonne.
1 imp. gallon contains 277·274 cubic inches and
1 U.S. gallon contains 231 cubic inches, but
1 litre measures 1 cubic decimetre.

(*b*) *Simplification of calculations.*—The foregoing section indicated that the scientific basis conduces to conciseness of conception, but the simplification of all ordinary calculations is almost beyond expression—"simply marvellous" as Sir Benjamin Baker said. To a man who has been used all his life to writing down 77 as a result of multiplying 11 by 7 whatever the denomination, how insane it must seem to be told that

11 articles at 7d. cost 6s. 5d.
11 ,, 7s. ,, £3 17s. 0d.
11 pounds at £7 per cwt. cost 13s. 9d
7 ,, £11 ,, ,, 13s. 3¾d.
11 pints at 7d. per quart cost 3s. 2½d.
11 quarts at 7d. per gallon cost 1s. 7½d.

and what must he think of the process by which such wonderful results are secured.

In a paper on the "Steam Path of the Turbine" read by Dr. C. P. Steinmetz before the American Society of Mechanical Engineers * it was stated that where an investigation extends over several branches of science the "incongruous mixture of heterogeneous units called the English system" is so cumbrous that it is far simpler to translate the premises into the metric system and to carry out the work in the metric system, even if the results have to be expressed in English measures.

Under the head of simplification I think it is fair to put engineering drawings. What a mixture of dimensions we get now. Even where restricted to English measures we get feet, inches, and quarters, eighths, sixteenths, thirty-seconds, sixty-fourths, and mils.

$1\frac{3}{16}''$ is liable to be misread for $1\frac{3}{8}''$,
$1'\ 1\frac{1}{4}''$ to be mistaken for $11\frac{1}{4}''$ or even $111\frac{1}{4}''$,

whereas under the metric system every dimension large or small can be expressed in millimetres and automatically translated when the higher unit needs to be expressed.

(*c*) *Mechanical calculator.*—Perhaps, however, we must look for the most enthusiastic appreciation of the metric system a few weeks after its adoption from the ordinary clerk and accountant when he finds that whatever his business may be and whatever the nature of his calculations the ordinary decimal calculator, or even the slide rule, will give him all the results he wants.

What developments in the use of mechanical calculators may be expected when the same simple and inexpensive machine will serve for every kind of business and every kind of merchandise.

(*d*) *Education.*—It has been stated that of 221 head masters who reported upon the subject in 1903, 212 expressed unreserved support of the metric system, as its introduction was estimated greatly to economize school life,

161 masters estimated the time at 1 year
30 ,, ,, ,, 2 years
6 ,, ,, ,, 3 ,,

(*e*) *Internationalization.*—The inconvenience of want of uniformity of international measures has been im-

* *Proceedings of the American Society of Mechanical Engineers*, 1908, vol. 30, p. 273.

pressed even upon the "man in the street" during the war, when he has been constantly faced with the difficulty of knowing whether the advance was on a 10-mile or a 10-kilometre front, whether we went forward a mile or a kilometre, and what the difference was.

This inconvenience is enormous to engineers and others who have constantly to deal with works of foreign and of American authorship and to make comparison of results recorded in different denominations.

The difficulty applies even in English measures alone, as, for instance, when, in two articles upon the same subject printed in *Engineering* the results were expressed respectively in cwt. per sq. inch and in tons per sq. inch.

Similarly with almost every kind of ironwork, some dimensions are expressed in feet and some in inches, or even in special gauge numbers.

Scientists, whose work is international, are practically compelled to express their results in international terms, even if they also use the English measures.

IV. Disadvantages of a Change of System.

(*a*) *General.*

(1) *English measures well known.*—That there are appreciable advantages presented by continuance of the present procedure cannot be questioned. As a nation of shopkeepers our measures have come to be known by merchants of all nations and in many cases our practice has become practically international. Somebody showed that the sizes of men's hats in Paris were ruled by the English practice, and explained that in order to keep within the law the nomenclature of the sizes had been revised so that hats of British sizes 6″, 6$\frac{1}{8}$″, 6$\frac{1}{4}$″, 6$\frac{3}{8}$″, etc., become sizes numbers 1, 1$\frac{1}{2}$, 2, 2$\frac{1}{2}$, etc. If it is a matter of practical importance that the sizes of hats shall be based upon gradations of $\frac{1}{8}$ in. there will certainly, in any law made here, be nothing to prevent that standard being maintained, nor even against the actual dimensions being used to denote the size. True, under compulsory adoption it might be technically illegal for the hatter to sell a hat at so much per inch.

(2) Again, the unit of capacity of a ship is the ton-register, equal to 100 English cubic feet, although the ton measurement of cargo is only 40 cubic feet. Yet this typically British rule-of-thumb unit is still of world-wide acceptance, even by the metric countries.

All such convenient conventions would, or could if desired, be retained, although it might be found convenient to express the 100 cubic feet in metrical measure. In the same way no doubt we should continue to use foolscap; but the dimensions which are now 13$\frac{1}{2}$ in. × 8$\frac{1}{2}$ in. would later on be expressed as 343 mm. × 216 mm.

Whatever advantages, however, may be admitted in the British measures, their continued use shuts us off from any advantages that may be presented by a truly international system.

(*b*) *Cost.*

(1) *General.*—The objection to the change that has to be taken most seriously is perhaps the matter of cost. Every opponent refers vaguely to the enormous cost involved in making the change. There can be no doubt that the cost to the community in the aggregate will be very great indeed, but this should be kept in its right perspective. The cost would not be a charge in bulk. It would be borne in relatively small sums by businesses according to the turnover. The small business would have to disburse once for all a few shillings for a set of new weights. Progressive retailers during the last few years have "scrapped" not only their weights but their scales in favour of direct-reading balances. Those balances could be corrected to the new weights for a relatively very small sum. The same would apply to butchers' steelyards which, without any revolutionary change, a few years ago replaced other machines scrapped as a result of a Board of Trade Order.

(2) *Engineering work.*—Similarly with a big engineering firm, the cost of the change for templates, gauges, meters, dies, etc., will for the most part only precipitate normal renewal, and will be a mere decimal point of the regular expenditure under many overhead charges, such as postage.

Probably even in regard to a large proportion of specially expensive measuring instruments the makers will be able to devise methods of altering rather than scrapping, while in other cases there will be little objection to or inconvenience in use of conversion tables. In fact the rule for capable people applies here, that difficulties are made to be overcome—raised by the fearful, razed by the cheerful.

(3) *Estimates. Taring of railway trucks.*—As an example of groundless fear, many of us were present at a meeting where a great railway engineer showed how the comparatively simple process of re-taring all the railway trucks would cost about £400,000. But I understand that railway trucks are re-tared normally (where facilities exist) when they come into the shops for repair, and the general manager of one great railway advised me that it would appear to be quite a minor matter; while another gave me the works history of three representative trucks built in 1908, 1909, and 1910 respectively, which were each re-tared twice within five years of building.

Shipbuilding.—In 1895 the President of the North-East Coast Institution of Engineers and Shipbuilders, when advising the then Prime Minister (Mr. Balfour) that his members were unanimously in favour of the change, stated that at his own works with a wages bill of £2,500 a week the cost of the change would be little over £100.

(4) *Effects on existing plant.*—Another aspect of the change gives great and groundless scope for the fearful. There would not be the slightest need to alter the dimensions of machines—toolmakers might even continue for years to make 3$\frac{1}{4}$-in. lathes if they wished, and no one would be "one penny the worse."

It must not be understood, however, that generally using the present measurements and giving them metric nomenclature is adoption of the metric system. We should ultimately use round figures in the metric system as we do in the English and should, for example, not stock 1-in. rod and call it 25·4 mm. but should have 25-mm. rod as the standard item.

This scrapping idea is really fanciful in many cases. In regard to meters, for instance, people who can read a gas meter in cubic feet and check the account at x per 1,000 cubic ft. would not seriously object to having to convert their reading into the corresponding metric measure. It would be no worse than a certain water company whose meters registered cubic feet while the charge was per 1,000 gallons.

(*e*) *Loss of mental and manual facility* (*Habit*).—One aspect of the change that perhaps more even than the cost will be felt to bear hardly upon the individual is the loss of expertness and facility that is bound up with the existing practice. Here more than anywhere breadth of vision and generosity of purpose are most needed. People often speak as if the idea was to think and work in feet and inches but to speak and calculate in centimetres. What we really have to visualize is the difference between on the one hand the existing conditions, with every English-speaking person using to some extent the English measures and all who have foreign businesses using in addition another system; and, on the other hand, the metric system alone being used by all for thought and word and work, the present tables being of interest only to the historian and the statistician. Which of these two conditions is the better? And how much the better? When I contend that the all-metric condition would be greatly superior, and when I prove, or even only claim, that the change would be worth effecting I have to recognize, and do so sympathetically, that there must be an intermediate period during which the conditions will undoubtedly be complicated for a vast number of people.

Most people, however, will readily adapt themselves to the new conditions, and for those who cannot, facilities will exist. For instance, (i) Housewives who know well the present price of sugar per lb. will at first only know that 66 mils per kilogram is a fair price, by seeing on the table that it is about the same as 6½d. per lb.; and such tables showing equivalents will be on exhibition in every shop. Or (ii) the head of a firm might continue to think and speak of ½-in. bolts long after such things had ceased to be used; and his subordinates would only explain to the juniors that he meant 12-mm. (or even 10-mm.) bolts.

(*d*) *Dual stocks*.—Of course in commerce during the transition stage the two things themselves would actually exist: at first the stock of ½-in. bolts would predominate, and at last only the 12-mm. bolts would be obtainable except as a special order. For many a long day we should continue to think of distances in miles, but when we had to pay in kilometres we should gradually get to think in kilometres.

(*e*) *Difficulty of working in decimals*.—It is a little perplexing to know how best to counter this objection, because so many opponents of the metric system contend that it would be better to decimalize the English weights and measures. But really the difficulty has already been overcome. The English mechanic is quite used to working to mils, i.e. 0·001 in., and occasionally carries the division to the fourth place as 0·0001 in.

(*f*) *Correction of drawings*.—For the most part there need be no corrections. At present in works and drawing offices where a few drawings to metric scales are handled no confusion results. How much less would drawings to the familiar scales need special treatment in the transition stage. But really the references to old drawings are not very considerable. I had a return taken which indicated that of a certain group of about 7,000 dimensioned drawings fewer than 300 were referred to in a year, and of these only 100 were more than four years old. That is, allowing for duplicate references, not 1 in 100 of the older drawings is ever needed.

(*g*) Again, with ordnance maps, etc., we already use eight standard scales, including one for the Land Valuation Department. Practically all measurements from them must be taken by map measurers, which are very inexpensive instruments; and it would be a very simple matter to have them adjusted to read kilometres instead of miles to the same scale. The proper scale for an ordnance map, however, is what is called the "natural scale"; that is, a scale which, as in an ordinary drawing, is a fraction of full size. Three of our eight standard sizes are to natural scale: 1 : 1,000,000 (0·06336 inch to mile), 1 : 2,500 (25·344 inches to mile), and 1 : 1,250 (50·688 inches to mile).

I have set out the present standards side by side with an alternative natural-scale metric series. The vast improvement presented by the latter to the user 10 years after adoption, when few of the former would exist, is I think self-evident.

Present Scale and Denomination	Ratio	Proposed Denomination	Ratio	Equivalent
Miles to inch	1 to	mm. to km.	1 to	Inches to mile
15·782	1,000,000	1	1,000,000	0·06336
10	633,600	2	500,000	0·12672
4	253,440	4	250,000	0·25344
2	126,720			
		10	100,000	0·6336
Inches to mile		20	50,000	1·2672
1	63,360	40	25,000	2·5344
6	10,560			
25·344	2,500	100	10,000	6·336
50·688	1,250	200	5,000	12·672
		400	2,500	25·344
		1,000	1,000	63·363

V. Conditions of Introduction.

There can be no doubt that some appreciable inconvenience will have to be faced by the community when the transition from English to metric measures begins. It would appear that this inconvenience would be less in the immediate future than at any later time, because our ordinary standards have been so rudely assailed by the war and we can effect the change virtually in process of getting back to normal. For example, if we ever get nearly back to the pre-war letter rate of a penny for 4 oz., the change might make it 4 mils per hectogramme.

Further, great masses of our men who will be returning

from France will be to a limited extent familiarized with the French coins and minor measures.

In fact, it is at least as easy to magnify as it is to minify the inconvenience. If as a matter of fact no difficulty is experienced in workshops where both systems are in use, why need we shrink from the simple process of making the complete change.

A few approximations between the two systems would be very useful if memorized :—

e.g.	1 kilometre	= about 5/8 mile,
	1 metre	= $1\frac{1}{10}$ yards,
	1 centimetre	= about 2/5 inch,
	1 millimetre	= 1/25 inch,
also	1 sq. metre	= about $1\frac{1}{5}$ yards,
	1 litre	= $1\frac{3}{4}$ pints,
and	1 ton	= about 1,000 kilograms,
	1 cwt.	= „ 50 „

VI. Compulsory Adoption.

Mr. Ingalls, President of the American Institute of Weights and Measures—which is merely the United States Anti-Decimal Association—says he argues "not against the metric system but rather against the propaganda for the *compulsory* adoption of it." Precisely, that is all that the most virulent opponent need ask for, because on that principle in these modern days he can safely depend that no reform that touches the individual pocket or the convenience of vast numbers of the community can be secured. "Let people who want to get up an hour earlier in summer-time do so, but don't make it compulsory" was the broad-minded argument, agreement to which would have robbed us absolutely and infallibly of a priceless boon. So these opponents know that the London and North-Western Railway Company cannot carry goods on a metric basis while any other railway company in the country does not; that a metric letter post is unthinkable while the confectioner sells sweets by the ounce and the grocer sugar by the pound; and that, so long as the Post Office measures parcels by the inch, the draper cannot sell linen by the metre. We, who in these days are used to compulsory limitation of the coals we may buy, need not break our hearts if we should be compelled to buy it by the metric tonne. We have been "free" to use the metric system voluntarily for 20 years. With legislators, bankers, men of science, engineers, schoolmasters, shipbuilders, chambers of commerce, and trade protection societies advocating its use, it is surely time that we made up our minds that the general interests of the community demand settlement of the matter.

VII. Decimal Coinage.

(*a*) *British bankers' system.*—Although the subject of coinage is very closely associated with that of weights and measures the two are really quite distinct and are capable of separate treatment. This is well illustrated by the facts that, while the writer of an article in *Nature* deplored that the *Electrical Review* by associating advocacy of a change of the monetary system with the claim for standardization of units had thereby jeopardized the success of the effort to secure the metric system, the Institute of Bankers recommend the adoption of decimal coinage as a first step towards the introduction of the metric system.

The Institute of Bankers this year adopted the report of a committee appointed to consider the whole subject, which recommended the introduction of a decimal system based upon the present gold standard with one pound as the unit. This was subsequently agreed to by the Association of Chambers of Commerce of the United Kingdom and by the Decimal Association. The pound would be divided into 1,000 mils, the whole scheme being as follows :—

		£	Mils
Gold or Notes	Sovereign	1·000	= 1,000
	Half-sovereign	0·500	= 500
Silver	Double florin (4s.)	0·200	= 200
	Florin (2s.)	0·100	= 100
	Half-florin (1s.)	0·050	= 50
	Quarter-florin (6d.)	0·025	= 25
Nickel (scalloped)	Ten mil piece	0·010	= 10
	Five mil piece	0·005	= 5
Bronze	Four mil (about 1d.)	0·004	= 4
	Three mil („ ¾d.)	0·003	= 3
	Two mil („ ½d.)	0·002	= 2
	Mil („ ¼d.)	0·001	= 1

This scheme presents the advantage of giving a clean-cut series of coins that cannot well be confused with any other system. It involves no break with the fundamental basis of British finance, maintains both gold and silver coins at existing values, necessitates only a 4 per cent variation in the value of the bronze coins, and gives an improved range of low-value coins without increasing the total number of different coins issued.

(*b*) Internationalization of coinage is in most respects not very desirable. If, however, it were possible to secure uniformity of coinage throughout the British Empire, perhaps with silver and bronze coins legal tender only in the country of issue, but with only one pattern of gold coins current everywhere. Those coins would be an expression in gold of the unity of the Empire, and I suggest that "Imperial" would be an admirable name for this new symbol of Empire.

I have sought to place before members "a case" for the adoption of the metric system. Limits of space, apart from want of ability and of authority, would prevent me from putting "the case," but I have endeavoured as briefly as I could to present some advantages, and to state fairly and meet squarely the main objections. On the assumption that, apart altogether from my effort, the case has been made, it remains to me finally to suggest as to :

VIII. "When ?"

Replacing standard weights of retail traders would be a fairly considerable matter. It might be better to let local authorities decide within a time limit the date of introduction in their several districts—the

only restriction being that in every shop during the transition period there should be only one system of measures used, and that the actual system in use should be prominently notified. For example, if the Act provided that on and after (e.g.) 1st January, 1919, all transactions should be carried through on the metric system, on and after that date in every shop there would be exhibited, besides suitable conversion tables, a notice that "Scales, Weights, and Measures used are Old Style" or "Scales, Weights, and Measures used are Metric."

Therefore the local authority would notify that on and after (say) 31st March, 1919, all scales, weights, and measures used in dealing with the public must be on the metric system. This would spread the demands upon scale makers over a longer period and thus facilitate the change.

All printed matter should be supplied by the State —another job for the Post Office.

When I was a schoolboy, I was told it would be "soon." Generations of schoolboys have come and gone since then, and millions of years of schoolboy time have been paid for by the parents and wasted on learning the great British muddle of measures. In that time not foot-rules and scales and weighbridges and templates and jigs, but factories and works and stores and railway stations have been rebuilt and re-equipped at vast expense, and we are still squandering millions of days every year at the beginning of life in order to save possibly the same time (certainly not more) in later life of the earlier generation once for all.

Opponents quite frequently recognize that the metric system is bound to come.

There can be no doubt that every year that we delay adopting it the difficulty and the expense of introducing the system are increased. Therefore the logical and reasonable procedure, with proviso that due time be allowed for the necessary preparations, is DO IT NOW.

APPENDIX.

CHRONOLOGY.

(Abridged from the *Electrical Review*.)

1824. On discussion of decimal coinage in the House of Commons a "pound and mil" system was recommended.

1841. After the destruction by fire of the Houses of Parliament, the Commission for the Restoration of the Standards of Weights and Measures reported in favour of the decimal system.

1843. } Further favourable reports.
1853. }

1859. A Select Committee of the House reported against a change in the coinage pending reform of the weights and measures.

1862. A Select Committee reported in favour of the adoption of the metric system.

1892. The Conference of the Chambers of Commerce of the Empire resolved that introduction of the decimal system was urgently needed. (Similar resolutions were passed also in 1900, 1903, and 1912.)

1893. Trades Union Congress advocated the reform.

1897. Metric system made legal, but the enactment did not provide for any compulsion.

1902. Sixty municipalities petitioned for the adoption of the metric system throughout the Empire. 292 Members of Parliament expressed their approval. Adoption was urged by the Imperial Conference.

1902. } The Associated Chambers of Commerce and
1903. } the Association of Trade Protection Societies
1904. } advocated compulsory introduction of the metric system and of decimal coinage.

1903. The Council of the Institute of Chartered Accountants passed a Resolution in a similar sense.

1904. The General Medical Council resolved that the metric system should be the only legal system for use in dispensing drugs. The Chambers of Commerce of Australia urged that the British Government should adopt the metric system.

Second reading of a Bill for the purpose passed the House of Lords.

1907. The House of Commons rejected, by the narrow majority of 32, a Bill providing for the compulsory introduction of the metric system.

1910. The Australian House of Representatives, by 35 votes for and 2 against, resolved that the metric system be adopted as soon as it became compulsory in Great Britain.

1914. The metric carat became the only legal standard for the weighing of gems, etc.

Barometer readings recorded in units of pressure founded on the metre-gramme-second system. Rainfall recorded in millimetres.

In the new edition of the "British Pharmacopœia" weights and measures are given in the metric system "in the expectation that in the near future the system will be generally adopted by British prescribers."

ELECTRICAL SIGNALLING AND CONTROL ON RAILWAYS.

By C. M. Jacobs.

(*Paper received* 14 *July*, 1917; *and read before* The Institution, 10 *January, and before the* Manchester Local Section, 15 *January*, 1918.)

Electrical methods are generally to be preferred for the operation and control of all the indications required by drivers and signalmen in connection with the two main divisions of railway signalling, viz.

(1) Block signalling, which has to do with keeping trains running on the same line of rails properly spaced; and
(2) Interlocking signalling, the function of which is to ensure that the points over which the trains have to pass are properly secured, and to govern movements in and about station yards and junctions generally.

An example of the advantage of electrical methods is to be found in the alteration which has recently been effected in signal aspects in North America, where the three fundamental semaphore indications "Stop," "Proceed with Caution," and "Proceed," are now being given by a single arm. This is possible only by working the signals electrically. Fig. 1 gives a comparison between the British and American signal aspects. The simplicity of the latter will be apparent.

Indication of Points and Signals.

The cardinal principle of railway signalling is that the tendency of failure shall be to cause the "Stop" to give such false indications, and the best-designed electrically-operated signal is not free from the defect. It is the business of the signalman to see that the semaphores give correct indications, and where there is any difficulty in his seeing them electric repeaters are provided; but these repeaters are not always as

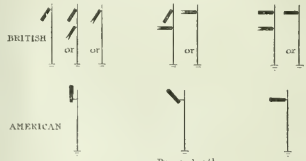


Fig. 1.

effective as they should be, due partly to their modest appearance and delicate character, which will not seem surprising when it is said that they operate with less than 0·01 watt. Electric lamp indicators would be more aggressive and therefore more effective, and there is much to be said for an audible indicator which would sound when the signal and lever con-

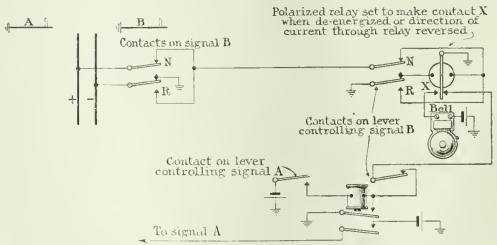


Fig. 2.

indication to be exhibited, an important thing to bear in mind when designing apparatus or circuits.

It is a serious matter for a semaphore signal to indicate "Proceed" when it should be showing "Stop" or "Proceed with Caution."

Mechanically-operated signals are particularly liable trolling it were not in agreement. Mere indication of the position of the signal, however, does not go far enough. In the case of block signalling it should not be possible to place a signal in the "Proceed" position unless at the same time the signal in advance is at "Stop." Fig. 2 shows an arrangement for effecting

this, including an audible indicator which sounds when the lever and signal are not in agreement.

Where interlocking signalling is concerned, it is necessary not only to prevent conflicting signals being off together, but also to have the signals in the "Stop" position if the points on the route controlled by the signal are not in their correct position. These safeguards can only be made thoroughly effective by working the signals, and detecting the points, electrically.

In an installation of electric detection of points and signals, a large number of wires have, of necessity, to be run close together, and precautions are required to prevent crosses or earths from causing the improper operation of the detector relays. On this account, and also in order to admit of faults being more easily traced, "common" conductors are to be avoided, while an independent source of energy for each indication circuit is to be preferred.

The McKenzie and Holland and the Westinghouse Power Signal Company's arrangement for this, where alternating current with a separate transformer is used for each indication circuit, is shown in Fig. 3.

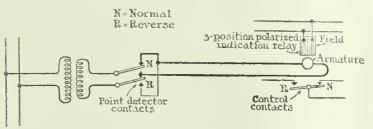


FIG. 3.

In the event of there being no independent sources of energy, each circuit should get current from independent tappings from the mains. Both these arrangements give continuous control or indication, and both are reasonably free from dangerous failure due to earths or crosses.

Electrical methods of point indication and control are mostly confined to power systems of signalling. They are, however, being introduced in connection with mechanical signalling installations.

TRACK CIRCUIT.

Signalling movements are further controlled by the presence on the rails of trains and vehicles themselves by means of track circuits. The principles of the track circuit are described in the paper read before the Institution by Mr. H. G. Brown about 11 years ago.*

The track circuit ideal is to detect anything on wheels across the rails. As generally installed, however, with a 4-ohm or 9-ohm relay and a 1-volt battery, a track circuit cannot be depended upon to detect anything which does not put virtually a dead short-circuit across the rails. The result is, that not only is such a track circuit unreliable for taking care of a single vehicle (which in combination with an unclean rail may mean a train shunt of anything up to 5 ohms), but it may occasionally fail to take care of a light engine or even a complete train.

* H. G. BROWN: "The Track Circuit as installed on Steam Railways." *Journal I.E.E.*, 1907, vol. 38, p. 107.

Track circuits may be divided into three classes:—

(*a*) Those which may be acted upon by complete trains only.
(*b*) Those which may be acted upon by a single vehicle.
(*c*) Facing-point track circuits, which being short have a comparatively high ballast resistance.

In the opinion of the author, in order that these track circuits may be quite reliable, they should be adjusted for minimum train shunts at infinite ballast of 5, 10, and 20 ohms respectively.

The adoption of anything approaching such standards will necessitate a higher ballast resistance, possible perhaps only by sub-division of the track circuit, a higher resistance relay, a higher battery resistance, and a track battery having a higher electromotive force.

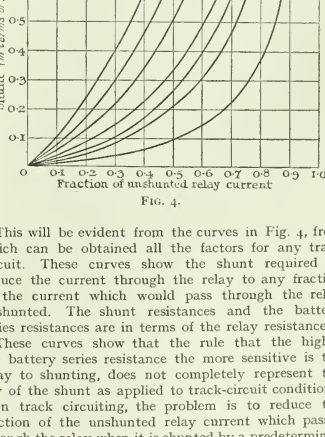


FIG. 4.

This will be evident from the curves in Fig. 4, from which can be obtained all the factors for any track circuit. These curves show the shunt required to reduce the current through the relay to any fraction of the current which would pass through the relay unshunted. The shunt resistances and the battery series resistances are in terms of the relay resistance.

These curves show that the rule that the higher the battery series resistance the more sensitive is the relay to shunting, does not completely represent the law of the shunt as applied to track-circuit conditions.

In track circuiting, the problem is to reduce the fraction of the unshunted relay current which passes through the relay when it is shunted by a predetermined minimum ballast resistance (this fraction of the unshunted relay current being known as the pick-up current) to a lower fraction known as the armature release current, which is usually 60 per cent of the minimum pick-up. The percentage difference between the shunts corresponding to the minimum pick-up and armature release is the same for all curves for the

same fractions of unshunted relay current. For efficient shunting, the lower part of the curves should be used; the fraction of unshunted relay current through the relay at minimum ballast should not be greater than 0·2.

Consider the curve in which the battery series resistance is 0·5 of the relay resistance, and let the minimum ballast shunt be 20 ohms and correspond to 0·2 of unshunted relay current, then the shunt at minimum ballast (20 ohms) equals 0·0833 of the relay resistance, which makes the latter 240 ohms.

TABLE 1.

Track Circuit Factors based on 0·2 of Unshunted Relay Current as Minimum Pick-up and 0·12 as Armature Release. Minimum Ballast Shunt 20 ohms, Armature Release Shunt 10·8 ohms.

Battery Ser. Res. / Relay Res.	Relay Resistance	Relay Pick-up	Unshunted Relay Current	Pressure of Track Battery
	Ohms	Amp.	Amp.	Volts
10	87	0·016	0·08	75
1	160	0·013	0·065	20·8
1/2	240	0·01	0·05	18
1/3	320	0·008	0·04	17
1/4	400	0·0075	0·0375	18·75
1/5	480	0·007	0·035	19
1/10	880	0·005	0·025	24·2
1/20	1,666	0·004	0·02	29·4
1/40	3,333	0·0026	0·013	44·4

TABLE 2.

Ratio of Armature Release Shunt to Minimum Ballast Shunt for Various Minimum Pick-up Currents.

Fraction of Unshunted Relay Current at which Relay Picks up with Minimum Ballast Shunt	Armature Release Shunt for 40 per cent Reduction of Minimum Pick-up Current=60 per cent of Pick-up
0·025	0·593 of minimum
0·05	0·587 ballast shunt
0·1	0·574 ,,
0·2	0·545 ,,
0·3	0·512 ,,
0·4	0·473 ,,
0·5	0·428 ,,
0·6	0·375 ,,
0·7	0·31 ,,
0·8	0·23 ,,
0·9	0·13 ,,

The standard type of track relay of this resistance requires about 0·01 ampere as the minimum pick-up current, so that the unshunted relay current must be 0·05 ampere, to drive which through the unshunted relay plus the battery series (0·5 relay), i.e. a total of 360 ohms, calls for a battery pressure of 18 volts. If the armature release current is 60 per cent of the pick-up current it equals 0·12 of the unshunted relay current, the corresponding shunt being, from the curve, 0·045 of the relay resistance, i.e. about 11 ohms.

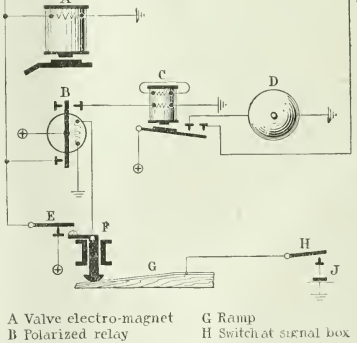
It is not sufficient to reduce the difference between the pick-up and release properties of the relay, if no regard be had to the value of the shunts which produce the maximum differences in the currents through the relay.

The ratio between the battery series and relay resistances only determines the voltages of the track battery. From Table 1 it will be seen that the most economical arrangement is when the battery series is about one-third of the relay resistance.

Table 2 clearly shows the advantage of taking a low fraction of the unshunted relay current for the minimum pick-up current.

AUTOMATIC TRAIN CONTROL.

Experience has shown it to be desirable that signal control should be exercised directly in the cab of the railway locomotive. The subject is a very controversial one, there being differences of opinion as to the character of the control required and as to the means for effecting communication between the road and the train.



A Valve electro-magnet
B Polarized relay
C Slow-acting relay
D Bell
E Switch opened by lifting of shoe
F Shoe
G Ramp
H Switch at signal box
J Battery at " "
⊕ Positive end of engine battery
⏚ Mass of engine and earth
{Negative end of engine battery connected to mass}

FIG. 5.

The Great Western Railway has had in use for the last 10 years a fairly extensive installation of automatic train control, a general outline of which will be found on page 777 of Mr. Acfield's paper * on "Development of Main Line Signalling on Railways." As this

* *Journal I.E.E.*, 1915, vol. 53, p. 763.

system is based upon certain definite ideas, and as certain developments have recently taken place, some further information in regard to it may be of interest.

In the first place it is recognized that safety in railway locomotion, like safety in all other kinds of locomotion, is dependent upon a good look-out, and on that account that there should be a minimum of interference with the driver consistent with the object sought to be obtained. This minimum is the indication of the distant signal which it is assumed may be missed by the driver. The Great Western system has accordingly been purposely limited to this signal. It is further considered that the control apparatus should be subservient to the driver, who is and must remain primarily responsible for the running of the train; he may be warned in such a way that his train will be automatically pulled up if he is not taking notice, but when he is alert there must be no question of taking—at perhaps a critical moment—the control of the train out of his hands.

Further views—and these were observed in designing

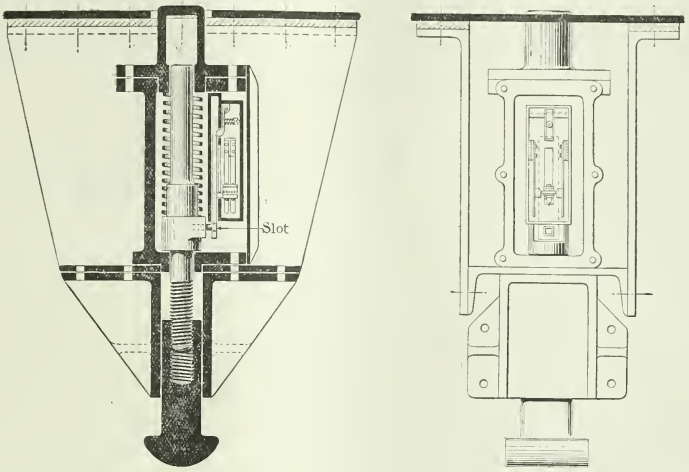


FIG. 6.

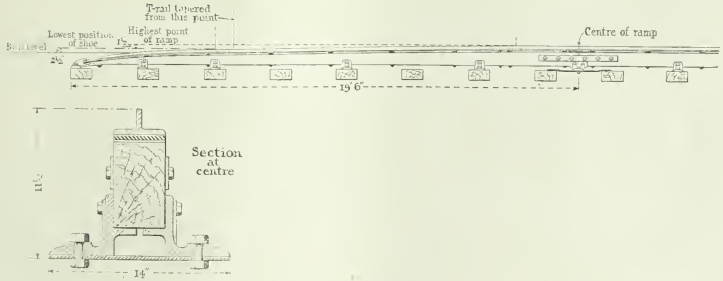


FIG. 7.

the scheme—are that the operation of the control on the train must be dependent neither upon a movable appliance on the line (on account of the known weakness of movable appliances, particularly mechanically-operated signals) nor upon the positive making of an electrical contact. Also, in order to comply with the cardinal principle of signalling, it was considered essential that the control apparatus should be practically tested each time a signalling position is passed and that "Proceed with Caution" should then be indicated if there is any failure.

The means for communicating between the line and the train have constantly been under review, but no satisfactory alternative to the original method has yet been found. A non-contact method would have been preferred, but so far no such scheme has been considered practicable.

Fig. 5 shows the latest arrangement of the cab apparatus.

The primary operation is the de-energization of the electromagnet controlling the valve admitting air to the train pipe. In the case of trains moving at high speeds (80 miles per hour and upwards) over a 40 ft. ramp the period of effective opening of the switch in circuit with the electromagnet may be less than 1/5 second. There has been no difficulty in the armature releasing with this period of interruption. Any difficulty experienced so far has been to maintain an uninterrupted electrical contact with the ramp during the time the switch is open. This has been met by introducing a slow-acting relay, a current impulse through which, due to the operation of the armature of the polarized relay connected with the mass of the contact shoe, is sufficient to cause the armature of the slow-acting relay to keep the switch—during the time it is mechanically open—short-circuited.

The slow-acting relay also controls a bell circuit, so that when the current is picked up from the ramp the bell sounds for a definite period. This is a positive "Proceed" indication, useful in foggy weather and during falling snow, besides showing that the apparatus is in order. In some quarters a positive "Proceed" indication is not considered necessary or desirable, but it may be pointed out that an apparatus which only indicates "Stop," in the absence of this indication implies by inference that the signal is at "Proceed," a questionable method of signalling.

The plunger of the contact shoe (Fig. 6) is provided with a spring having an initial compression of $1\frac{1}{2}$ in. under a load of 250 lb. and a final compression of 3 in. under 530 lb. So strong a spring has been found to be necessary, not so much for obtaining a good electrical contact between the shoe and the ramp, as to keep steady the plunger to which the switch is attached and prevent the latter momentarily opening. By making a slotted connection between the plunger and the switch as shown, instead of directly attaching one to the other, combined with the characteristics of the slow-acting relay, it is found possible to use a weaker spring, thus reducing the wear on the case-hardened face of the shoe. The insulation resistance between the shoe and the mass of the engine averages about 2,000 ohms.

The ramp (Fig. 7) has an insulation resistance in wet weather of about 1,000 ohms.

The line pressure at the ramp is about 18 volts. It is limited by the difficulty in maintaining primary batteries in country districts, otherwise a higher pressure would be preferable.

The disposition of the shoe and ramp, viz. in the centre of the running rails, is the most practicable and convenient, and this, as safe signalling is an important factor in railway operation, may become a reason favouring the adoption of alternating current for railway electrification.

Gravity-sorting Sidings.

Mr. Acfield * has described an installation by the British Pneumatic Company for operating the points of gravity-sorting sidings.

As showing the possibilities of electric operation and control, an ingenious system—the invention of M. Descubes—on somewhat similar lines, and until recently in use at Lumes, near Charville, on the Eastern Railway of France, is worthy of mention. A replica of this system would no doubt by this time have been

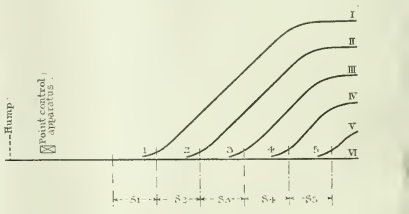


Fig. 8.

in operation in this country but for the same cause which has led to its temporary abandonment in France. For simplicity the system is described as applied to the lay-out of sidings (Fig. 8).

A signalman is stationed between the top of the hump and the first pair of points and he has a number of electrical pushes corresponding to the number of sidings. The number of the siding into which each wagon (or group of wagons) is required to go is chalked on the front of the wagon. The wagons are pushed up over the hump and then released one after the other to run, spaced a few yards apart, down the grid. As each wagon approaches him, the signalman depresses the push corresponding to the siding required, and without any further attention on his part the points are moved in the necessary order at the proper time.

The track circuits, S1, S2, S3, etc., are provided, S2 between the fouling point of siding I and the fouling point of siding II, S3 between the fouling points of siding II and siding III, and S1 the same length as the others in advance of the fouling point of siding I.

The points are worked by electric motors with

* *Loc. cit.*

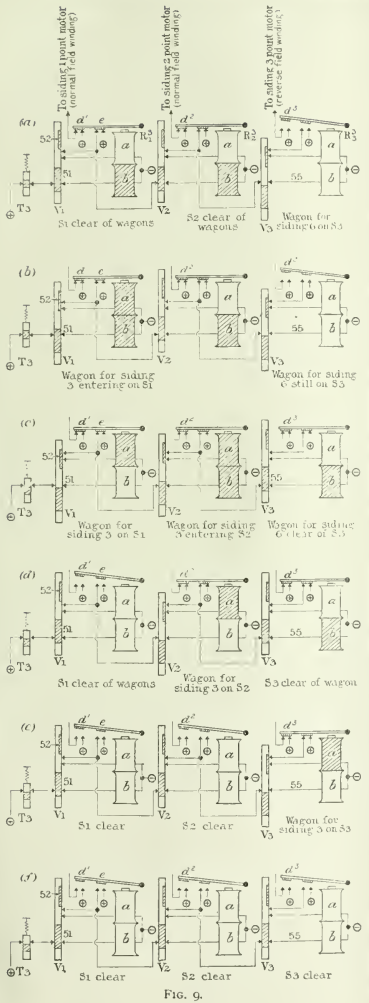


Fig. 9.

two field windings, so as to be reversible. The motors are controlled by relays with two windings called progression relays. The motors complete their work in about 3/5 second. For siding I there is one progression relay controlled by track circuit S1, and the signalman's push for siding I. For siding II, two progression relays controlled by track circuits S1 and S2 respectively, and the signalman's push for siding II. For siding III, three progression relays controlled by track circuits S1, S2, and S3, and the push for siding III, and so on.

Fig. 9 (*a*, *b*, *c*, *d*, *e*, *f*,) shows the sequence of operations in getting a wagon into siding III, following a wagon going into a siding farther on, say VI.

T3 is the push for moving points 3 for siding III. This push when depressed is held down magnetically as long as current passes through the push. V1, V2, V3, are the armatures of the relays of track circuits S1, S2, S3 respectively and R^1_1, R^1_2, and R^1_3 the progression relays—controlled by track circuits S1, S2, S3—these latter relays controlling the motors of points 1, 2 and 3 so as to be right for siding III.

Fig. 9 (*a*) shows what happens when the signalman depresses the push for siding III, push 6 having previously been used for the wagon for siding VI, which wagon it is assumed is at that moment on track S3. The current flows through push 3, through contact 51 of armature V_1 of the relay of the track circuit S1 (which track is unoccupied), to winding *b* of progression relay R^1_1, attracting its armature and closing contact *d* of siding I point motor, thereby moving points 1 for the straight line if they are not already in that position and also closing contact *e*, putting current through V2 (S2 being also unoccupied) to winding *b* of relay R^1_2, and confirming the position of points 2 through contact d^2; but as S_3 is occupied, contact *e* on armature of R^1_3 does not cause winding *b* of R^1_3 to be energized.

Turning to Fig. 9 (*b*), wagon for siding III now enters on track S1, wagon for VI still being on S_3, armature V of track relay S1 commences to fall and connects through contact 52 battery through *e* to winding *a* of R^1_1.

In Fig. 9 (*c*), armature V_1 is completely down, opening the circuit of winding *b* of R^1_1 and causing push T3 to resume its normal position. R^1_1 remains energized by winding *a* acting as a stick relay.

The wagon for siding VI is now supposed to be clear of S_3 and the wagon for III entering S2. The armature of V2 commences to fall, energizing winding *a* of R^1_2, and track S_3 being clear V_3 makes contact 55 and winding *b* of R^1_3 is energized, closing the motor of points 3 reverse.

The remainder of the sequence will be readily followed from the diagrams.

Single Line Working.

The old British method of working single lines by means of tokens is on the whole the most satisfactory system which can be devised, and a large mileage of

the single lines throughout the world are equipped with electric token apparatus.

There are several forms of token instruments, but they are all based on the same principle and consist essentially of a magazine for holding a number of tokens, a commutator or reversing switch, and an electric lock.

Fig. 10 shows a type which has been introduced recently and which it is suggested has the merit of simplicity.

The instrument has a special key-way K, through which the tokens must be passed in and out, and in

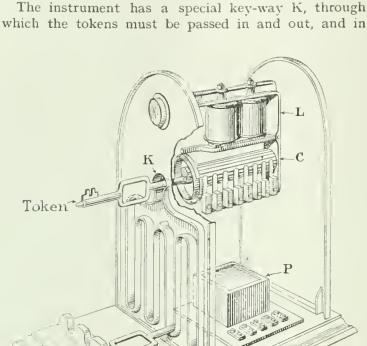


Fig. 10.

the process of which the commutator C must be turned by the token in a clockwise direction going in, and in a counter-clockwise direction coming out, the turning of the commutator in the latter direction being governed by the electric lock L, controlled in turn by the polarized relay P.

A number of token instruments are sometimes connected to one circuit at different points in the same section. This is useful for enabling trains to be run to intermediate sidings, and there put by for a through train to pass; also for enabling the permanent way men to obtain occupation of the line without having to depend upon flagmen for their protection. In this way considerable economies can be effected.

Power for Electric Signalling Purposes.

When in the early days of railway telegraphy electric repeaters were first introduced to indicate the working of signals, everyone seems to have agreed on an instrument which would work with a single cell of a primary battery, and to this day the efficiency of signalling apparatus is largely limited by the output which can be obtained from primary batteries. Moreover, there is an enormous number of these primary battery cells in use, as each signalling circuit usually has its own individual battery.

In large centres, at any rate, it should be more economical, and, what is of more importance, improved apparatus from the signalling point of view would result if, in place of individual batteries with limited output, current were to be obtained from a central battery of accumulators.

There are also cases where it might be an advantage to use an alternating-current supply.

Limitation of Electric Signalling Methods.

In conclusion a word may be said as to the limitations of electric signalling methods.

A good deal more is generally expected of an electric signalling appliance than of a mechanical one, and rightly so. There is, however, sometimes a tendency to expect what almost amounts to infallibility, an idea which has probably been fostered by somewhat enthusiastic advocates of electric systems who talked about the elimination of the human element. Consequently, when one day an electrical device fails on the wrong side, operating officers may become unduly apprehensive, particularly as the explanation of an electrical failure is a little more difficult to understand than is the cause of the failure of mechanical apparatus.

No electrical system of signalling can be absolutely safe or absolutely fool-proof, and unless it be intelligently designed, installed, and maintained, it can only be comparatively safer than mechanical systems or a code of rules. An electrical system cannot eliminate the human element, because it has to be put in and looked after by a human being.

Discussion before The Institution, 10 January, 1918.

Colonel J. W. Pringle: The remarks I wish to make are of a general nature and non-technical. I hope that experiments will be made more widely with the three-position signal. Action in this direction would, I think, enable us to go one better than the old proverb, and to kill three birds with one stone. The other "birds" I refer to are the advantages of the upper quadrant movement of signals, and the use of orange, or some other third light, for signal purposes. The last looks to me a very desirable "bird." I agree with the author that electric lamp indicators are likely to prove more efficient than the delicate and unobtrusive electro-mechanical type of repeaters now commonly in use. The author's observations upon track circuits have interested me greatly. His suggestions for dealing with track circuits under three classes are, I think, likely to be helpful and to have practical results. The reliability of the track circuit is a matter of first im-

portance. If, therefore, as the result of experiment and discussion, some common lines can be agreed upon for general acceptance, and standardized, much good will result. The last point to which I wish to refer is automatic train control. I wish to draw attention to requirements which in my opinion any approved system of control should be able to fulfil. Experiment has shown that the large majority of preventable accidents on railways have been due either to mistakes by signalmen, or to mistakes by enginemen. We hope to find in automatic train control a safeguard against the second of these alternatives. The author observes that signal control should be exercised directly on the train. It is necessary also, since an engineman has to observe the road before him—not only with the object of seeing signals, but for the purpose of avoiding obstacles on the road, deformation of track, and so on—that the system of train control adopted shall not be of a type which, by obviating the necessity for viewing outdoor signals, will create a tendency to neglect observation of the road. For this reason cab signalling—by which I mean the provision of miniature signals representing the position of the fixed outdoor signals—is nowadays in less favour. Other systems of control provide audible indications, and direct action on the breaking apparatus. If the accidents for which we are seeking a safeguard were entirely brought about by failure to observe and act upon the indication given by the warning signal or distant signal, it would not be necessary to do more than the author suggests, namely, to limit its application to the warning signal; but, unfortunately, experience has proved that a considerable percentage—probably one-half—of the accidents due to mistakes by enginemen have resulted from misreading of home or starting signals. This misreading has frequently taken place after the distant signal has been duly observed. If, therefore, a system of control were adopted which does not admit of direct action upon the train at "stop" as well as at "warning" signals, the safeguard would only cover about 50 per cent of the cases we are seeking to prevent. Again, as regards the likelihood of danger from interference with an engineman by any system of train control, I am not persuaded that it is advisable to follow theory to the extent which the author advocates. We can follow theory too far. If an engineman knows a fixed "stop" signal is at danger, he will certainly do his utmost, by using the brake power at his disposal, to bring the train to a standstill at the earliest possible moment. If with any system of train control the same result can be obtained automatically, and without introducing any fresh element of danger, such a system of train control will, I think, have practical advantages sufficient to warrant a departure from the general theory that interference with a driver is inadvisable. For this reason, the effect produced by any system of control at warning and stop signals respectively should, in my opinion, differ in degree. At a distant signal it should be left in the hands of the engineman to neutralize, or to increase, the effect of the automatic brake application according to the necessities of the case; but at a stop signal the result desired is to bring the train to a standstill as rapidly as possible. Recent experiments have shown that this can be obtained with both high-speed passenger and goods trains, whether fitted or unfitted with a continuous brake. In the case of stop signals it is preferable in my opinion that the control of the train, so far as the brake power goes, should be taken out of the hands of the driver, until the train has come to a standstill. We have had a number of years' experience on the Underground and Tube Railways of a system of control of this type. The effect on these busy lines of taking the control of the brake power out of the hands of the driver when he passes a stop signal at danger has not been found, I understand, to minimize his sense of responsibility for observation, or to bring about other dangers.

Mr. R. T. Smith: On page 130, col. 2, par. 3, the author says: "The disposition of the shoe and ramp, viz. in the centre of the running rails, is the most practicable and convenient, and this, as safe signalling is an important factor in railway operation, may become a reason favouring the adoption of alternating current for railway electrification." This statement appears to be ambiguous. If, on the one hand, the author considers that direct-current electrification necessitates a fourth conductor rail in the centre of the four-foot way, while alternating-current electrification does not, I wish to dispel that illusion. The history of the fourth or insulated rail in the electrified track is, I think, that in some of the early Tramway Bills the Admiralty got a clause inserted making it compulsory to have an insulated return on all tramways within a certain radius of Greenwich Observatory, for fear that the earth currents might interfere with the Observatory; and this provision was copied into some of the early railway electrification Bills. Other railways connecting with them were obliged to adopt the fourth rail, hence its prevalence in London suburban electrification. I would remind the author, however, that the North-Eastern, the Lancashire and Yorkshire, and the London and South-Western electrified tracks have got no fourth rail. If, on the other hand, the author means that on electrified lines the traction current and the track-circuiting current should be of different types, and if he then chooses direct current for signalling and imposes alternating current for traction, I think it is a case of the tail wagging the dog. I am personally of opinion, after the success on the Lancashire and Yorkshire railway of the protected positive conductor rail supplied at 1,200 volts—and there is no reason why it should not be equally successful at 1,500 volts—that in this country, with its comparatively short lines (I mean compared with the hundreds of miles of electrified line under one ownership which are found in the United States), direct current of moderately high tension will be used for traction and that system will of course employ the running rails for the return current. If that be so, wherever track-circuiting is used on such electrified lines, alternating current for track-circuiting is a necessity. I wish to ask the author if the cab-signalling arrangement shown in Fig. 5 has yet been worked out for alternating current used on the ramp, combined of course with a battery on the locomotive itself. If the scheme put forward in the Report just issued by the Coal Conservation Sub-Committee advocating a national as opposer to the present

parochial system of electricity supply in this country is adopted, and if that is emphasized by the Report of the Committee now sitting on Electric Power Supply, I think it is likely that in the near future there will be more alternating current available near railways for such purposes as track-circuiting. I would suggest to signal engineers the extended use of alternating current for track-circuiting as being one of the things they must occupy themselves with in the near future. This is a tabloid paper. There are many important things tucked away in odd corners, and one of the things one may easily lose sight of is that in order to fulfil the conditions laid down on page 137 the author advocates or suggests very much higher voltages for track-circuiting than have been so far generally used. Personally I hardly see how those higher voltages can be supplied by batteries; they would have to be provided by some general supply system at non-standard voltage, which would again fit in with an alternating-current supply for track-circuiting. Track-circuiting at present, with certain important exceptions, is almost entirely dependent on batteries for its source of supply. In country districts where there is no general supply of electricity it must be done at present by a battery, and there are few articles of common use, I think, which are so misunderstood and badly treated as the secondary cell. My own department on the Great Western Railway deals at three depots with the maintenance and charging of a considerable number of track-circuiting cells, and I find that last year we charged 20,000 cells, and this represents only about one-third of the total number of cells charged in the year. It will be seen, therefore, that even on one railway where track-circuiting is only sparingly used, it is a big business. I should like to suggest to members interested in the manufacture of batteries that they should pay the very greatest attention to the production of a light battery which can remain on open circuit for the longest possible time. These batteries must be charged, carried by train to stations within the nearest reach of the signal box, deposited on the platform, carried over the track, and, in the process, receive the hardest possible treatment. It is therefore most important that in this particular branch of the work every effort should be made to produce the lightest possible secondary cell which can remain for the longest possible time on open circuit.

Mr. A. Hurst: I should like to refer to the position of the arms of what is known as the three-position signal. All signal engineers are, I think, agreed, in principle, that it is their duty to give the greatest possible facility to the drivers for the true interpretation of the signals exhibited, so that it may conduce to the safety of the public. In order to do this, we must exhibit signals which cannot in any way be mistaken for anything else; and unfortunately, the three-position signal is not free from this defect. If we look at Fig. 1 we shall see that a driver is always liable to mistake an "all right" signal for the opposite line for a "caution" signal on his own line. This is clearly wrong in principle and I think, therefore, that the question of the three-position signal wants to be very carefully considered. In America, I believe, a large proportion of the lines is in open country, and the track is made probably with larger curves and freer from impediments to the view than the lines in our more crowded country, so that possibly this point does not affect them so much. Where, however, there are complicated junctions and great difficulty in arranging signals so that they can be seen conveniently and correctly by drivers, the difficulty which I have alluded to is very much greater than it would be otherwise. Incidentally I should like to refer to the question of orange lights. The Railway Clearing House was very strong on the question of an orange light a short time ago, but they have practically given it up, for the following reason: Orange is the colour of the spectrum which the greatest number of men cannot see. In cases of colour blindness the first colour which is obliterated is orange, the second is blue, the third is yellow, the fourth is green, then red, and the last is violet. Clearly, therefore, the introduction of an orange light would be the very worst one possible, because the highest percentage of men who are partially colour-blind could not see it. I do not quite understand the author's remarks in the last paragraph of the second column of page 136, where he says: "In the case of block signalling it should not be possible to place a signal in the 'Proceed' position unless at the same time the signal in advance is at 'Stop.'" That would not work. When a man sets a road through a station he sets the farthest signal first, the advance starting signal; then he proceeds to pull off the starting signal, then the home signal, and last the distant. If, therefore, he could not pull off the distant signal unless the signal in front of it were at Danger or Stop, he would run the risk of stopping the train unduly, and I think, therefore, there is something in the author's mind which limits this clause to some condition which is not quite apparent from the paper. I am very glad to see one point made very clear, namely, on page 137 (col. 1, par. 2) the author rather condemns the use of a common conducting wire. When the first automatic signalling system was put down on the North-Eastern Railway we had a common wire for about ten miles; the result was that we were always getting a number of false indications, because with a common wire it is always possible to have a fault some three or four miles away from a signal, and a second fault developing to work that signal when it ought not to be worked, and possibly by a battery situated at some considerable distance from it. We got over the trouble by cutting the line into sections, and as a last resource through the junctions, which were more complicated, by taking a single wire for the up line and another for the down line. In that connection I should like to refer to another part of the paper, at the foot of page 142, where the author advocates larger local batteries instead of so many separate independent currents. I should like to point out that if this were adopted, it might lead to the same trouble I have just mentioned. I should next like to say a few words in regard to the electric stop apparatus. In this case the author has described what I have always considered to be the best apparatus designed in this country for the purpose. It was originally

called a fog signalling apparatus, but now it is called automatic train control. This apparatus is perhaps the best that can be devised, because it is applicable to the engines of all trains, whether such trains are fitted with automatic brakes or not, or whether they are passenger, goods, mineral, or other trains. The electrical train stop which we have heard of in regard to the District and other underground railways of London is not, I think, quite so much fitted for use on trunk lines where there are long and very heavy goods and mineral trains to work, and therefore possibly the author had in his mind that the apparatus which he was advocating, and which I consider to be really the best so far devised for general purposes, was more suitable for mixed traffic than other apparatus which have been designed for a similar purpose. The difficulty will always be that should, from any cause, the part of the apparatus on the engine or on the permanent way be displaced or removed, then the train stop becomes faulty and does not fulfil its duty. Nor is this an altogether unheard-of thing. I have known many cases where owing to a platelayer leaving a sleeper, for example, higher than it ought to be on a level crossing, the apparatus on the engine has been removed, and I have known of engines running 60 miles without the driver knowing that the apparatus was faulty. I do not say, however, that that condemns an apparatus which provides for giving a second or "all right" indication to the driver as in this apparatus. I should also like to refer to route levers. This arrangement is used very much in France and consists simply of a single lever which when pulled sets a number of points and the corresponding signal or signals referring to a route and is quite distinct from the levers working individual pairs of points and signals. The idea is that it saves labour, but there is one difficulty in adopting it and it is this—that where we have what we call special locking, it is very difficult to apply, the result being that the special locking which is required for safety is very often omitted. What I mean by special locking is this: Suppose we have three levers, A may lock B if C is pulled, but A does not lock B if C is normal. Now, if we set a series of points and we include such locking as that, it follows that if it is worked by one lever, when we have pulled that one lever the locking which is in vogue electrically is not the same as the position of the levers in the frame. That is the difficulty, and to get over the difficulty, as I say, very often the locking, which is most important for safety, has to be omitted.

Mr. W. J. Thorrowgood: In speaking of the main division of signalling, the author makes no mention whatever of the "lock and block" system, although in Fig. 2 one of the important principles of the Syx "lock and block" system, which has been in use for many years, is shown, viz. that before permission is given for a train to pass into the section, and before the starting signal is pulled "off," the signal in front, that is, the home signal, must be in the "on" position. The upper quadrant signal is not universal in America. The latest returns from the Interstate Commerce Commission show that 17·2 per cent of the railway lines in America are controlled by what we call automatic signalling, 34·4 by non-automatic signals, and 48·4 per cent are not protected with signals at all. There is very much to be said for the upper quadrant signal, and if we were starting afresh there would be very good grounds for adopting it under certain conditions. But again looking to America, there is another system, namely, daylight signalling. It is arranged that there are three lights, one with a green, one with a yellow, and one with a red lens; these are illuminated by electrical glow lamps day and night. When the green lamp glows, it indicates that the train may proceed; when the yellow lamp glows, it indicates that the train may proceed with caution; and when a red light glows, the indication is "stop." Those indications are used for automatic signalling. For interlocking—what we call mechanical signalling—there are two sets of these colour signals arranged to give six indications. Recently on the Chicago and Milwaukee Railway 444 miles of railway have been provided with these daylight-colour-indication signals. Then there is the "position" daylight signal on the Pennsylvania Railway, in which four white electric lamps are used If the four lamps are arranged horizontally, it represents "danger" or "stop." If the four lamps are arranged diagonally in the upper quadrant, at an angle of 45°, the indication is "proceed" with caution; and if the four lamps are arranged vertically, it indicates "proceed." Both these systems of signalling remain unchanged day and night. There is a hood over the lamps to shade them from the sun. In England, until recently, the semaphore in the lower quadrant was practically universal, i.e. we had a universal signalling language as far as the position of the arm went. Before that universal signalling language is superseded by a better one, it seems to me that all classes of signals should be considered—daylight, mechanical, electrical, upper quadrant, and lower quadrant. The advantage of the daylight electric lamp signals lies in the fact that there is no moving mechanism outside on the ground, but merely a relay in a case. With white daylight position signals, the colour-blindness difficulty disappears. With regard to signal repeaters, we do not always measure the efficiency of an electromagnetic arrangement in terms of watts. There are thousands of these electric signals repeaters on British railways, and they are efficient—at any rate on the London and South-Western Railway—and give correct indications. With an arm repeater, such as we use, the shape and position of the signal can be indicated. A light may be more striking, but it only gives one indication, and in addition to that it cannot be used universally, insomuch that at small country stations it is difficult to provide a battery. I think the author goes a little too far when he says that the safeguards mentioned can only be had by working the signals electrically; for even in that case the indications of the signal depend upon the track circuits, point detectors, etc., as do the mechanical signals with electric slots, the electro-pneumatic, the low-pressure pneumatic, and other systems. I fail to see at this time, with the knowledge we have of electric circuits, why there should be any difficulty in regard to common con-

ductors. There is no reason at all why we should not have a common positive conductor between the extreme limits at the station, taking off the current at places where we want it, through suitable resistances. At Clapham-junction there has been for several years now such a common positive conductor, which goes from Clapham-junction South to Queen's-road. At one time the direct current used for track circuits, and the secondary circuits of the point detector mentioned in the paper, were all supplied from this common positive conductor and no practical trouble arose. Furthermore, such a common conductor facilitates electrically repeating the functions on the ground, so that all the wiring for the electric interlocking can be done in the cabin, and any fault that may arise is immediately evident to anyone who is familiar with the system at the point. I have read that part of the paper dealing with track-circuiting with great interest. I quite agree with the author that the shunt resistance of trains should be very much higher than it is at the present time. He divides them into three classes, but in the case of class (*a*) it is quite possible—in fact it has been known to happen—for single vehicles to be left on running lines. It appears, then, that the shunt resistance for such lines should be the same as for class (*b*). I must again protest against the improper use of terms. In the discussion on Mr. H. G. Brown's paper in 1906.* I raised the question of the use of the term "ballast resistance" for what is really insulation resistance. In the paper "battery series resistance" is also mentioned. Now all resistances in a circuit are in series with the battery; they may not be in series with one another, but they are in series with the battery. What is meant here, is the internal resistance of the battery plus any resistance which is put in between the positive or negative terminal of the battery and the rail. This is a regulating resistance. Then again a new term is introduced in the shape of "armature release current." The current does not release the armature of a track-circuit relay. The armature is held up by the attraction of the electromagnet, and it is pulled down by gravity and by spring pressure. "Drop-away current" describes more nearly the action taking place than the other expression, and the term is now in general use for this action. The curves in Fig. 4 are of great interest, and deserve to be studied very seriously, but the pressure of 18 volts which the author proposes is rather high for a single track circuit. Table A, herewith, compares the results under similar conditions, with a 4·5-ohm relay in use at the present moment. The condition is that the minimum ballast resistance is 20 ohms, though the minimum in the case of a track circuit in practice is more likely to be 2 than 20 ohms. If we take the case of a 4·5-ohm relay, and arrange for the maximum regulating resistance, viz. 5·396 ohms, then the maximum shunt resistance is 11·25 ohms, which is well above the 10 ohms mentioned in the paper for class (*b*). If we take the 4·5-ohm relay, and use a pressure of 6 volts and a maximum resistance of 50·74 ohms, we shall find the shunt resistance to be 16·9 ohms, a higher one still. But if we look at the watts used on the relay it will be found that with the relay which the author proposes, the watts are 0·024, while on the 4·5-ohm relay the watts amount to 0·03645; that is to say, the 4·5-ohm relay can be 50 per cent robustly constructed than the other. Of course the insulation resistance will not remain constant. Say it

* *Journal I.E.E.*, 1907, vol. 38, p. 117.

TABLE A.

Comparison of Track-circuit Relays with Coils wound to 240 ohms and 4·5 ohms.

Function	Relay, 240 Ohms	Relay, 4·5 Ohms	Relay, 4·5 Ohms
E.M.F. of battery, volts ..	18	1	6
Regulating resistance, ohms	120	5·396	50·74
When track circuit clear :—			
P.D. on regulating resistances, volts	15·6	0·595	5·595
P.D. on relay, volts ..	2·4	0·405	0·405
Total current, milliamperes	130	110·25	110·25
Current through relay, milli-amperes ..	10	90	90
Current through insulation resistance, milliamperes	120	20·25	20·25
Total power, watts ..	2·34	0·11025	0·666
Power of relay, watts ..	0·024	0·03645	0·36450
Power of regulating resistance, watts ..	2·1	0·0738	0·63055
When relay armature drops :—			
P.D. on regulating resistance, volts ..	16·56	0·6625	0·6625
P.D. on relay, volts ..	1·44	0·3375	5·3375
Total current, milliamperes	138	122	111·5
Current through relay, milli-amperes ..	6	75	75
Current through insulation resistance, milliamperes	72	16·875	16·875
Current through shunt (i.e. train), milli-amperes	60	30·125	9·723
When relay short-circuited :—			
Total current, milli-amperes	150	185	118·25
Total power, watts ..	2·7	0·185	0·709
When minimum insulation resistance 20 ohms :—			
Maximum shunt resistance, ohms	24	11·25	16·9
When insulation resistance 30 ohms :—			
Maximum shunt resistance, ohms	17	9·4	13·16

increases to 30 ohms, then the shunt resistance with the 240-ohm relay will be 17 ohms; with the 4·5-ohm relay and 1 volt, 9·4 ohms, and with the 4·5-ohm relay and 6 volts, 13·1 ohms. My last point is with regard to alternating-current track circuits. The first alternating-current track circuit was installed at Richmond, and I had the honour of putting it in. What I want to say, with all the emphasis I can, is that the shunt resistance should be as high in the case of an alternating-current track circuit as in the case of a direct-current one. The shunt resistance asked for by the author is 5, 10, and 20 ohms, but the shunt resistance of an alternating-current system, as used to-day, is somewhere in the neighbourhood of 0·2 ohm. I think that some further investigation, on new lines, needs to be undertaken with regard to alternating-current track-circuit apparatus.

Mr. R. J. Insell: I quite agree with the author that electrical working of signals is to be preferred. The wire rope generally used in this country is to my mind only one of the signs of the conservative manner in which we are in the habit of conducting our business. Signals being the means by which safe working of our railways is assured, it is of the utmost importance that everything possible should be done to provide such appliances as will give the greatest security. The exposed connections to mechanically worked signals are not only a source of obstruction to men on the line, but are open to many other objections. Obstruction in the free run of the wire may cause the all-right signal to be shown when the danger position is necessary, and it is open to unauthorized persons to work the signals without the knowledge of the signalman and the safeguard of the interlocking in his box. So far as the Great Western Railway is concerned, we have introduced a large number of electrically worked signals, generally in the case of distant signals, and on one new line opened a few years ago all the distant signals are so worked. With regard to failures, I think I prefer the failures involved with electrically worked signals. A failure may cause an arm to remain either at "danger" or at "all right." In the former case safety should be assured, and in the latter any danger can be avoided if the signal is interlinked with the block telegraph. Perhaps after the war it will be possible to make some progress on the railways generally in regard to this question. With regard to the American three-position signals, I consider these a great advance on our present practice. One of the chief things which impressed me in the course of travelling over a few thousand miles of railways in the United States was the simplicity of the signalling. One might say that all the stations and junctions were the same so far as the signals were concerned. This is brought about by the signals not only giving three indications, but by the position of the arms indicating the speed required. It is very rarely that one sees more than three arms on one post. Here I think we have the advantage of adopting something which is the outcome of experience gained in America, whose signalling formerly was entirely British. So far as track circuits are concerned, it is impossible for them to be dispensed with, and it is up to the electrical engineers to make them efficient. I am sure the permanent way engineers realize the importance of track circuits, and will render every assistance in providing a road suitable for the work. The system of automatic train control described by the author should not be confused with the "train stop" as used on the London Underground Railways. Automatic train control is necessary to assist drivers of trains and enables them to bring their trains to a stop at a predetermined point, and in the event of failure on their part the apparatus is designed to do it for them. So long, however, as a driver is alert, the control of his train remains in his hands, and this seems to be necessary. The "train stops" on the Underground Railways are provided at stop signals and come into operation in the event of the signals being passed at "danger." This makes it necessary to provide an overlap which will give a sufficient margin to enable a train to be brought to a stand before reaching the danger zone. On trunk lines this would not be possible, as stop signals denote a definite geographical position beyond which it is dangerous to go, and the only effective stop would be a catch point combined with the automatic train control. It is difficult to believe that, with efficient automatic train control, train stops or catch points are at all necessary. Accidents of a serious nature due to drivers ignoring signals are fortunately rare and, generally speaking, automatic train control if adopted would possibly eliminate them altogether. Electricity already plays a very important part in railway signalling, and when we are able to obtain a cheaper supply of power, there will be ample scope for the electrical engineers to deal with signalling on a much greater scale than is possible to-day.

Mr. A. E. Gott: A point about track-signalling arrested my attention in the reading of the paper. It is a matter for surprise to learn that such low voltages are used in these circuits and such small differences of current employed in operating the relay magnets between the hold-on and release positions. The lack of reliability obtained recalls early experiences in the control of electric motors for driving certain classes of industrial machinery wherein it was imperative that the machine should be instantly stopped in the event of certain contingencies arising. The ordinary method was to short-circuit the "no-voltage release" coil with a push switch, but as this coil usually was excited by the shunt-field current the method was similarly unreliable even when substantial cables were used for the push circuit. The problem was solved by separately exciting the no-voltage release coil, allowing it to form part of a dead resistance across the supply; thus on a 200-volt circuit it absorbed about 30 volts and carried about $\frac{1}{4}$ ampere. The resistance usually consisted of an ordinary 16 candle-power incandescent lamp, easily replaced when broken. Short-circuiting the release coil in this way proved so reliable a release, even when the wires were run a considerable distance, that I have never known the method to fail. I suggest that the solution of reliability in reference to track circuits consists in the adoption of a similar method.

Mr. F. A. Lart: I fear that my remarks will be regarded rather in the light of destructive criticism.

My experience in railway and locomotive working is that the greater the simplicity in signalling apparatus the greater is the efficiency. When I was at Crewe I saw carried out what were probably some of the first experiments in this country in mechanical signalling. Various methods were tried exhaustively—electrical, pneumatic, hydraulic, electrical-pneumatic, and electrical-hydraulic. These experiments did not develop into any practical working, probably for the reason that the mechanisms were found unreliable and too complicated. This is a point I should like to emphasize —the electrical control and working of signals is far too complicated. The apparatus involved is very liable to get out of order and paralyse the entire plant, at any rate locally. The old, simple, method of the wire and lever for working signal arms, points, and interlocking, seems to me to be absolutely reliable. I would emphasize the undesirability of relieving either the signalman or engineman of any of their responsibility as regards actuating and observing signals. The exact position of a signal can be indicated to a driver in the cab of the engine by some simple appliance placed between the rails quite efficiently, and with more reliability than by any system of electrical communication. I consider it very desirable that the signalman and driver should be clearly apprised of the position of distant signals especially, as with fast and heavy trains over-running of signals is more common than might be supposed. It seems to me that the only objection to the old-fashioned mechanical system of hand-working is the occasional variation, due to fluctuations in temperature, in the wires so that on long stretches it is not always possible to get a signal arm to come "off" at the proper and unmistakable angle. In my own experience of locomotive-working, whenever a driver encounters an invisible or doubtful signal, owing to fog or for any other reason, he invariably proceeds with great caution, shutting off steam and getting the train well under control in view of a possible stop at the home signal or earlier.

Mr. H. M. Proud: I propose to confine my remarks to that portion of the paper which deals with track circuits. I have been led to make these remarks through the fear that persons who have not studied this branch of signalling may get the impression that track circuits as at present installed are unreliable, and that to make them adequate for the work they have to perform they must be installed in a much more costly manner. The last paragraph in the first column on page 137 is, I think, likely to make it appear that the present-day practice is to install track circuits which will not detect anything which does not put "virtually a dead short-circuit across the rails." I am aware that a number of track circuits have been badly installed in the past, and I fear that some are still in existence, but the large majority of railway signal engineers are now sufficiently familiar with the subject to realize the necessity of properly installing track circuits, and I think that it is only fair to state that it is the aim in all modern installations, including those which are fitted with relays of both 4-ohm and 9-ohm resistance to adjust the circuits so that the relays shall open their contacts with a train shunt having values of from 1 to $1\frac{1}{2}$ ohms. I believe that the author will agree with me, as I am aware that quite good train shunts are obtained on the track circuits installed on the railway with which he is connected. It would appear that he wishes still further to improve the shunting of the relays, and he has given the shunt values at which in his opinion the relay should open its contacts. It is extremely difficult to criticize these values, but one could hardly conceive of a train whose total resistance (all the wheel contacts in multiple, including those of the engine) would anywhere approach 5 ohms. One would have expected to have found a class for track circuits installed on lines constantly used by traffic, such as main lines. It is not quite clear why a different train shunt should be required for the track circuits in classes (*b*) and (*c*); surely there can be no more onerous duty than detecting the presence of a single vehicle, by which I assume is meant a single pair of wheels. Of course it is easier to get a high-resistance train-shunt on tracks which have a comparatively high ballast resistance. Has the author taken advantage of this fact and for class (*c*) put his standard unnecessarily high? He has set for us a very high mark of attainment, but has given us in the form of the graphs in Fig. 4 a ladder with which to reach it. The bottom rungs, however, are missing and I should like him to supply them. He has shown us how we can decide on the best values for series and relay resistance, and for battery voltage after we have determined: (1) the minimum value to which the insulation of the track circuit will fall; (2) the relation of the series resistance to the relay resistance; (3) the ratio between the current in the relay when the insulation of the track circuit is at the minimum, and the current in the relay when the insulation of the track circuit is infinity. These three values are the rungs which are missing. Track-circuits as at present installed are not so unsafe as one would be led to suppose from the author's remarks, and the more sensitive adjustment suggested by him can be obtained at a less expenditure of power than would appear from a cursory glance at the paper. My conclusions are that the graphs shown in Fig. 4 will be most useful, but I think that a good deal of experience will be needed before we can arrive at the missing values, and I do not consider that we can get them (especially the first one) other than by the results of such experience. In brief, I think that the author has put into our hands another useful tool to use in track-circuit calculations, and we have to learn how to use it.

Mr. P. M. Baker (*communicated*): The chief point which arises out of this paper appears to me to be that our signal engineers have dealt with, and built up a system by the process of piecemeal improvements and alterations which have not tended in the direction of producing a homogeneous system. I venture to point out that this criticism applies to the subject matter of the paper. Summarizing the situation which arises, the paper appears to call for (*a*) improved arrangements in connection with "block interlocking" and (*b*) improved methods of conveying the indications which result to the driver and compelling him to act upon the same. Thus, for example, the upper quadrant

signal, even with three-position indications, is only a minor detail of the working—a detail even which is of doubtful utility, seeing that (1) the simplification which results is not as great as that at first sight indicated in Fig. 1; (2) the information conveyed to the driver is not by any means as complete as that given by the British arrangement; and (3) its adoption would involve a very dangerous transition period. In connection with the block interlocking question, and arising directly out of the statement at the foot of page 136, it might be pointed out that the question of general principle there involved is that which arises from our practice of having signals normally at danger. If we adopted the American scheme—a scheme which is practically involved in the three-position signal—we are practically compelled to adopt the general principle that the signal shall indicate the condition of the road in front of the driver. Under the present English system the signals do not indicate the condition of the road except immediately before the arrival of a train. The working could be much simplified, probably without losing any of its safety, by adopting the American arrangement and so avoiding the difficulty mentioned on page 136. In support of this contention one might point out that practically all automatic signalling is worked on this principle and it is doubtful whether the universal adoption of the American scheme would not have many advantages. Reverting to the paper, I desire to point out that although in general very strongly in favour of electrical operation of signals, I do not think one should place all the blame for accidents caused by signals to the credit of the mechanical operation. In stating that "mechanically operated signals which are particularly liable to give such false indications," etc., the author allows us to lose sight of the fact that mechanically-operated signals are moved as a result of the indications of electrical instruments in the cabin. The mechanical man tends to look at things from the opposite point of view and frequently says, even to-day "a good man with a lever, a wire, and a semaphore are quite good enough for me," or, "these electric gadgets are too complicated and sensitive for practical men," quite forgetting that his combination is useless without good block instruments and that the best men fail at times—the worst frequently—as every engineer who has seen anything of railway work, particularly abroad, will realize. Another important point, arising practically directly out of the paper, appears to be the question of the provision of power for signalling purposes. A general tendency on the part of the manufacturers concerned has been that of making their apparatus work with the smallest possible current in order that battery troubles may be avoided as far as possible. The battery question, with its heavy maintenance costs, must always be a difficult one to deal with, particularly when the staff available is of low calibre. It is probably felt most in track-circuit work where, with saturated ballast and sleepers, the maintenance of efficient working becomes difficult, and I feel that the time is probably approaching when signal engineers might have the courage to inaugurate schemes involving the use of generators, small petrol electric sets or the like, for supplying the necessary current not only for instruments for track circuit but for operation of signals. It should not be difficult to organize a crowded piece of line so that a generating station near its centre could supply all the energy required for several stations in the neighbourhood, even if no public supply of a suitable character were in existence. Much very useful and very interesting work has been done by firms making signal and interlocking gear, but I feel convinced that a general broadening on the lines which I have ventured to indicate would probably tend to an all-round simplification and even in the long run lead to economy both in prime cost and in upkeep.

Mr. F. Downes (*communicated*): The author wisely calls attention to the weaknesses peculiar to electrical methods, but I think it is generally understood that these weaknesses can be overcome at reasonable expense with subsequent improved working, whereas in mechanical methods when transmission of energy is involved, many of the difficulties are unsurmountable at reasonable expense. I am particularly interested in his curves and tables referring to high-voltage track circuits, and I have worked out some examples where the ballast resistance, having been reduced by climatic conditions to a more practical figure, a high-voltage track circuit would become useless, whilst the low-voltage track adjusted for more usual conditions would still be operative. Ballast resistance appears to be the author's fundamental hypothesis, and will remain the least controllable factor in this part of the world owing to climatic conditions. The cost of sub-dividing the insulated sections so as to maintain a minimum ballast resistance approximating to even 10 ohms for all localities soon becomes excessive; I find a simple track divided into three sections doubles its cost, and with 10 divisions the cost approximates to that of five simple tracks, whilst the increased liability to electro-mechanical failures due to additional apparatus must be even greater. Doubtless the causes of the main difficulties can be very much improved if practical considerations are given to and values determined for:—

(1) The most satisfactory form of ballasting that signal engineers can recommend to be used, consistent with permanent-way requirements, bearing in mind that it may be necessary to apply it generally so as to cover the application of continuous track-circuiting.

(2) The minimum insulation resistance between running rails, per given length of road, with unfavourable climatic conditions of this ballast.

(3) The most satisfactory method of electrically bonding Mansell wheels so as to give the lowest possible electrical resistance between wheel tyres. Practice shows that the maximum need not exceed 0·1 ohm when leaving repair shops, but it is a moot point how long that figure obtains during running, and opens up the question as to whether other tests should be made apart from those carried out when vehicles are under repair.

(4) Consider whether some kind of non-insulating material (say carbon) could not be mixed with sand used for preventing wheel slipping.

Members of the Railway Signal Institution could obtain data so that constants could be agreed upon

and standard practice more readily followed. Track-circuiting, like other problems with several variables, will be more capable of solution by determining practical maxima and minima values for the variables and applying these in conjunction with the constant factors. I am of opinion that it will be found that two classes of track circuits could be economically standardized for all cases. By the courtesy of the North-Eastern, Great Western, and Great Eastern Railway officials I have travelled on locomotives over a section of their railways, each equipped with a system of cab signals or train control in which ramps and lifting contact shoes are used. All three systems worked correctly, and having been in practical use for some considerable time are considered to be reliable. The North-Eastern system applies to both distant and stop signals, the other two to distant signals only, so that it should now be possible for responsible authorities to agree upon the essential character of train control for general adoption. With the Great Western and Great Eastern the location of the ramps agrees, as does the effect of an electrically dead ramp, which produces the "danger" signal. By electrifying the ramps with uniform polarity and voltage for giving the "clear" signal, I believe both companies' engines could be controlled over either company's system; therefore, whether the engine equipment shall include a battery and be wholly electrical or be partly mechanical and eliminate the battery, can be decided by the respective companies and remain no longer a contentious point, any more than the precise form of fixed signals, all of which give similar significant indications. A third contention as to the means of effecting the control from the signalman to the train can be left for the future ideal system not requiring ramps and contact shoes. Until then I consider their use justifiable, and when the ideal comes along it should be capable of incorporating existing engine equipment minus the contact shoe. I anticipate that auto train control at distant signals only will be as equally effective in the elimination of drivers' errors, as is track-circuiting in preventing signalmen's mistakes; and as both safeguards are acknowledged to be needed, it is inconsistent to ignore either.

Mr. T. S. Lascelles (*communicated*): I agree with the author that electrical methods are generally to be preferred to mechanical ones in the operation of signals, but I wish he had elaborated this point a little more than he has done. The operation of signals by power, even at mechanical interlocking plants, has many valuable advantages, and it is to be hoped that it will speedily come into more extended operation in this country, for we are sadly behindhand in this matter as yet. All distant signals, and all heavily slotted signals ought to be operated by power, both in fairness to signalmen and drivers, and in the interests of safety. With mechanical signals constant difficulty is experienced in keeping the wires properly regulated, and the result is that one can continually see signal arms standing in a half and half position, which is very misleading and unfair to drivers. As signal engineers, our duty is to do all in our power to exhibit unmistakable signal indications to drivers, and especially with the class of signals to which I have referred, this can only be satisfactorily done by power operation. All the difficulties of slotting, with its cumbersome clatter of rods, wires, and weights, can be swept away, and the heavy work thrown upon the signalmen abolished. This is especially applicable to those railways which use "push-off" slots, which are mechanically unsound, and result constantly in false signal-arm angles, whilst they are exceedingly heavy to work. The author has emphasized the importance of proving that a signal is at "danger" before the next one in the rear can be lowered. This is particularly so where track circuits are installed, as it compels the signalman to replace his signals to danger behind each train. If this arrangement be not provided, a signalman can leave a signal permanently "off," and so defeat all the security afforded by the track locking. It is also desirable to prove that all signals are at danger for the line concerned before the "line clear" block signal can be given to the signal-box in the rear. Where lock-and-block instruments are in use this follows, as a matter of course; but where they are not, an arrangement such as the author describes is most necessary, though I think that it is hardly needful to go to such an elaborate scheme. It might be interesting to remark that the practice of causing an alarm bell to ring when the signal arm and lever failed to correspond was put into operation in the eighties at many places on the London, Chatham, and Dover Railway, in connection both with high and with dwarf signals. If we were to adopt the continental practice of double wiring for signals we should go a long way towards minimizing the danger of "hanging off." In his remarks on electrical detection, the author has drawn attention to its uses with mechanical signals. Here again is a case where electrical methods are safer altogether than mechanical. Mechanical detectors are both cumbersome and dangerous. The collision that occurred not long ago at Moorgate-street, Metropolitan (Widened) Lines, showed conclusively the danger that lurks in them, a signal being held falsely at "Line Clear" through the detector slides sticking. The absence of them also allows of freer working of the signals, a most desirable object. It is to be feared that the reason why such methods have not yet come into as much use as they ought to have done is due to the separation on most railways in this country of the electrical and mechanical signalling into separate departments, which is not conducive to a broad and comprehensive treatment of the subject, and results in overlapping and a too narrow outlook on the part of officers. The day has passed when a man can be called a signal engineer and only be acquainted with mechanical signalling—and the time has come to put the whole of the signalling, of every kind, under one department and chief, as has been done by the Great Western and South-Western Railways. I wish the author had made some reference to the alternating-current track circuit, as it is bound to come more and more into use, owing to its peculiar advantages in safeguarding against stray current dangers, and as he seems to look forward to the use of high voltages on the rails, voltages which would be something of a problem with primary batteries. I should also like to hear his opinions on the proposal to use a 2-ohm relay, put forward by the Railway Signal Associa-

tion of America recently. The Great Western system of automatic train control is very interesting. The author gives reasons for using such an arrangement only at distant signals, but I feel unable to agree with him. Experience has shown that drivers have ignored or misread "stop" signals after observing the distant signal, and have started from a terminal station against a starting signal, having, therefore, passed no distant at all. The consequences of running by a signal giving admission to a tunnel, an outer home signal, or a junction signal, may often be so very serious that we must be prepared with something to meet it, and I can see no future in a train-control system that cannot be applied equally to distant or stop signals and permit of shunting movements in the wrong direction with perfect facility. I should like to ask the author if any arrangement for giving an irrevocable stop at an adverse stop signal has been developed with the Great Western system. It is all very well to say we must not take control of the train out of the driver's hands. If a man runs by a stop signal at danger it is high time for such control to be taken away from him. And here it might be worth while to draw attention to another point concerning the observance of signals, viz. the driver's position on the footplate. On almost all lines in England the driver is put on the right-hand side, the very worst side possible, especially with the modern large-boilered engines and small cab windows, seeing that the signals are, with few exceptions, placed on the left of the line. The London and North-Western, and a few other lines, put the driver where he should be, on the left, and so do away with the danger that led to an accident a little while ago, of the driver relying on the fireman to observe a platform starting signal. That there is nothing in the right-hand argument about the difficulty of firing with the driver on the left, is proved by the practice of such a line as the London and North-Western. I should like now to refer to single-line working. I observe that the author considers the "old British method of working single lines by means of tokens" to be the most satisfactory on the whole. It is worth while inquiring into this for there seems to be a tendency to turn the token into a fetish. Where there is only one token the security is absolute, if a driver never leaves without it; but when there are several tokens, as in the modern electrical systems, the question is somewhat different. The possession of a token is not, in itself, an absolute safeguard, since there are several for the one section, and the real security lies, of course, in the mechanism of the instruments. The token merely becomes a register of the passage of the train. Therefore, if equivalent means can be found to register this, and equally reliable block instruments can be secured, the token can be swept away as a useless encumbrance. Track circuit, combined with well-constructed lock-and-block instruments can be made to give all the security afforded by tokens, without the waste of time involved in exchanging them, except, of course, where mechanical exchangers are used. Even then, however, time is wasted at crossing stations when two trains meet in taking the tokens from each train to the signal box and back in order to pass them through the instruments. I believe, therefore, that the further development of track circuit will lead to the abolition of the token idea, and then the driver will have only one set of signals, viz. the outdoor, on both single and double lines. Where tokens are used, all exchanging should be done mechanically—both in the interests of traffic working and for the safety of employees. Every year a number of minor hurts are sustained by men in effecting the exchange, even at very low speeds, especially by night, and it is to be hoped that exchanging by hand will everywhere become a thing of the past in due course. With regard to power for electric signalling, it is peculiar that no attempt seems to have been made in England to make use of the magneto generator for block-signalling, as is so extensively done on the Continent in place of primary batteries. At outlying country signal-cabins the magneto should prove very useful. A Continental signalling engineer recently told me that on no consideration could they ever think of reverting to batteries, after the economies and increased efficiency that the magneto had enabled them to effect. This system prevails in Belgium, Germany, Holland, and elsewhere. It is satisfactory to see the author pleading for careful maintenance and installation for electrical devices. Closely connected with this is the question of the education of employees, aiming at encouraging them to take an interest in all sides of their work and to improve to the utmost their technical knowledge. It is to be regretted that on many railways insufficient attention is given to this important question, with the result that many linemen are not fit to be entrusted with electrical devices, and hence the latter do not receive a fair chance. Linemen should be encouraged in every possible way to study the theory of the devices in their care, and be given facilities for seeing technical literature and reports bearing on all kinds of signalling. This is as important from the point of view of safety as it is from that of efficiency.

Mr. W. S. Roberts (*communicated*): I am particularly pleased to hear that the author is of opinion that the elimination of the human element is not the correct method to increase the safe working of the railways. I have been accused of having quite a touching faith in this element, and I am pleased to say I have to plead guilty to the charge, as being in my opinion the least likely item to fail. My reason for having such a faith is that I cannot conceive such a combination of mechanism which could operate signals and points, place detonators on the line, show a red flag or light when required, telephone to the next cabin to side-track a train or vehicle running away, and generally act in many ways in case of emergency. I am quite in agreement with the author that we must not expect infallibility from electric signalling methods, but I do think the nearest approach we shall obtain to infallibility is primarily through the human element, combined with the extended application of mechanical and electrical devices to assist him to carry out correctly the functions expected of him, and the automatic restoring of signals to the "danger" position by the passage of the train. The author has mentioned under "train control" that the control apparatus should be subservient to the driver; so also in my opinion should the mechanism for safeguarding the human element be auxiliary to

the individual, or as a noted French engineer of the Paris, Lyons, and Mediterranean Railway stated in 1895: "The most practical application of automatic working consists in protecting the train without giving the signalman a chance of seeing that this has been done, so that he may not relax his care." I think this equally applies to present-day conditions. Regarding the author's remarks that no electrical system of signalling can be absolutely safe or foolproof, although I am in agreement with him, we should strive to design to cover for these items as far as possible. This does not lead to simplicity of design. I notice the merit of simplicity is mentioned in connection with the token instrument (Fig. 10). I have not had any experience of this instrument and presume simplicity of design is referred to. I have had a very extended experience of token instruments, both from a designing and working standpoint, and I have come to the conclusion that simplicity in design does not lend itself to deal with the fallibilities of the human element as met with abroad. Token instruments are used far more extensively abroad than at home, and I have seen many types of mankind operating them. In some countries where the *morale* of the operators is very low, provision has to be made to endeavour to avoid what in this country would be considered to be criminal action on the part of the operator. Referring to the cardinal principle, we often claim as an accomplished fact that the failure of a signalling apparatus causes the "stop" indication to be exhibited. Unfortunately this is not always the case in actual practice, and so long as a physical operation is required to alter the "all right" or "proceed" indication of a signal to the "stop" or "danger" position, so long will the claim not be an accomplished fact The effort of course should be to select the operation least liable to failure, but I quite agree with the author that the signalman should be there to act in case of failure. With regard to electric repeaters, the author evidently is a believer in making a noise if the signal and lever operating the same are not in harmony, and I cannot say that I disagree with him. A very effective way of causing a fault to be remedied is something which creates a nuisance whilst the fault is on, but provision must also be made so that the nuisance cannot be removed instead of the fault. I was very much surprised to hear from the author that the general method of installing track circuits occasionally failed to take care of a light engine or even a complete train. I have always been apprehensive of the chances of this happening, but have been reminded that it is performing best when the least is heard of it. The human element to my mind is performing best when least heard of, and I should therefore again emphasize the use of the combination of the two, with the hope that the failure of the one might be detected by the other, or the more remote chance of the failure of both concurrently. With regard to detecting points, I am assuming that the author had in mind the opening of the circuit of the signal leads if the points were not in the correct position, instead of what is usual in the mechanical systems of a lock on the signal lever. As between the mechanical and electrical methods of detection, much can be said of the weakness of either, but in fairly large installations I should choose electrical detection as the better method. Respecting automatic train control, this is a subject which has been under discussion for many years, and innumerable systems have been devised. It should be in operation on all our railways. In fact, on several railways (chiefly those operated by electric traction) it is in operation with successful results. The author has, however, sounded the right note in my opinion, namely, that the subject is so controversial that added safeguards to our railway-working are being sacrificed whilst this controversy is allowed to proceed. The main trouble appears to be that each railway is anxious to have its own system, each of course believing it to be the best. I feel sure that if the interested officers of the various railways could meet, presided over by a chairman who is well versed in this subject, and who has the welfare of the whole of the railways at heart but is not connected with any particular one, a fairly simple and acceptable automatic train control could be agreed upon. When such an arrangement has been made, the Board of Trade would be well advised to make such a provision compulsory upon, at any rate, the portions of the railways responsible for express traffic. It is fortunate that railways have already adopted an interchangeable automatic brake system, for if the method had to be decided at the present day, we have so many competent engineers that they would all be wanting their own systems to be adopted, and controversy would be the cause of an indefinite delay and would considerably add to the difficulties of dealing with the question of automatic train control on our trunk railway system.

(Mr. Jacobs's reply to the discussion will be published in a later issue.)

DISCUSSION ON

"ELECTRICAL COOKING AS APPLIED TO LARGE KITCHENS."*

MANCHESTER LOCAL SECTION, 11 DECEMBER, 1917.

Mr. Bertram Thomas: It is very difficult to get any information about installations of this kind. There is no information published and very few papers are read on the subject. The author refers to the favourable tariffs now in force. I am quite aware of these, but I am always under an apprehension lest the station engineers should find it necessary to increase those tariffs if electricity is generally adopted as the cooking agent. I believe the low tariff was originally put forward at the time of the introduction of the metal-filament lamp, when there was a reduction of station loads and station engineers were very anxious to make it up. If electrical cooking is generally adopted so as to affect the station plant and the distribution of energy, it seems to me quite probable that the tariffs will have to be readjusted. We want some assurance on that point. In many cases the load comes on the peak and is not altogether a desirable load for a central station. The curves in the paper show that more than half-load comes on between 4 p.m. and 6 p.m., which is an extra load that must be added to the peak in many of the stations. It may be rather different in Newcastle where the load is mainly a power load, but in Manchester such a cooking load would be a very serious factor. Take, again, the case of London. If electrical cooking were introduced into restaurants doing business in the evening the trouble would be still worse. Therefore I cannot see that it is possible to maintain the present low tariffs. The author says that the three essentials are reliability, quick service, and efficiency, and he places them in that order, but I do not think there is any need to give prominence to any one of the three. Efficiency need never be sacrificed to reliability. Usually the trouble has been that the apparatus has not been well designed and has been rated too high—more through lack of experience than anything else. Very often the areas of the vessels have been too small for the ratings which have been applied to them. The question of terminals and the method of leading-in the current is a very serious one and receives too little attention. In the case of a very large installation for industrial purposes a number of bars used for box-making were electrically heated to a very high temperature and were also subjected to blows and vibration. Originally there was a good deal of trouble in dealing with the terminals and the connections, but after a little experience and by watching the results we were able to get these right. Some of those heaters have actually been in use for 10 hours a day for upwards of nine months. Of course that has nothing to do with large kitchens directly, but indirectly it has because of the effect on the public when heaters fail and have to be replaced. It is generally recognized that the solution of the cooking and heating problem was rendered effective by the production of nickel-chrome wire. It is a wonderful material. I think it is not produced in this country but is brought from the United States. It will stand any reasonable heat, but difficulty is now being experienced with the supports. In many cases mica has to be used as a support and by itself is not very satisfactory, as it will not stand a high temperature. If overheated, it disintegrates and the heater fails. That has been a very serious source of trouble with heaters generally. We are looking for a material which will do better than mica, but whether we shall obtain one I cannot say. Most of the failures have been due to terminals, leading-in wires, or supports. I do not think there is really any reason why the wire itself should fail if it is properly rated. In an oven at my own house I have a heater which has been used during four years two or three times every day and has so far never required attention. Even gas ovens would require some attention in a corresponding period. There is no reason why the larger ovens should not stand as well. In fact they should stand better than the smaller ones. The author does not seem to have gone closely into the question of water-heating. I do not think any large up-to-date kitchen can be established unless low-pressure steam is provided. Eventually we shall come down to the fact that we must use steam in an efficient kitchen. Then it becomes a question of how to produce that steam. If we take coal at 25s. per ton we can get 90,000 therms for a penny, and if we take electricity we only get 3,400 therms for a penny; therefore it does not seem a practical proposition at the present time to use electricity for heating large quantities of water. A kitchen cooking for 500 people would probably want 1,500 gallons of hot water a day for various purposes, and that means a very large consumption of electricity. We must therefore continue to use coal for heating water. Connected with that is the question of washing up. In Fig. 3 the wash-up troughs are placed in the middle of the kitchen, which does not seem an ideal arrangement, as the soiled plates, etc., would have to come across the counter where the food was being served out. Further, the washers-up would be in the way of the people handling the food. The washing-up ought to be carried out in a separate department and the dishes ought to be brought into that department without getting into the way of the food service at all. Apart from the question of position, it is necessary to wash up by steam if it is to be done effectively. I know an institution in Manchester where 600 people are catered for every day. In the past they had to employ eight people two hours after each meal to wash up the plates and dishes. A motor-driven steam-heated washing machine was, however,

* Paper by Mr. W. A. Gillott (see page 92).

installed, by which one man and a boy could wash up in half an hour after each meal. That is the only practical way and it is one in which steam must be used. If it is adopted, the washing trough must be kept outside the kitchen so as not to make it unpleasant for the people using it. Apart from that the wastage of crockery is enormously reduced. There is practically no wastage at all. The author appears to favour self-contained vessels, but I do not think that is a good scheme. It will be found that everybody wants to use his own vessels and does not wish to install new ones. Moreover, with the self-contained vessel the risk of destruction is much heavier. We have been led to believe that by electrical cooking we get an enormous saving in the weight of the meat. The results of some careful comparative tests indicate that as between gas and electricity there is very little difference in the loss of weight; it is about 3 per cent in favour of electricity. I think in the early days enthusiasts were quite prepared to eat food half raw if they could thereby demonstrate that there was a saving, and the amounts stated to be saved were sometimes ridiculous. I do not believe that policy has been successful, and in our own interests we ought not to continue it. Another point is the extreme ease of cooking by electricity. By the use of the thermometer, cooking can be made almost an exact science. That must lead to economy both in electricity and in food.

Mr. A. E. Jepson: One of the speakers in the discussion before the Institution (see page 102) said that difficulty had been experienced in balancing the load on the three-wire system and he suggested that more attention should be paid to high-voltage apparatus, say for 400 or 500 volts. There are difficulties in the way. The insulation of most of the insulators used, such as mica, enamel, and ceramic ware, decreases enormously as the temperature rises. I have known the insulation of a hot-plate to decrease from 40 megohms when cold to 1,000 ohms at 400° C.; while a slab of quartz 0·946 cm. 0·939 cm. × 0·1514 cm. changed from 95 megohms at 486° F. to 0·17 megohm at 1,013° F. In order to make water-boiling a commercial proposition for large quantities, where the cost of generating electrical energy is low, say 0·22d. to 0·28d., and if electrical power could be obtained for water-boiling at such a figure, with a properly lagged boiler having a low consumption there would be practically no heat lost; an extra heater can then soon bring the water up to boiling point when required. If there were no loss from radiation, convection, or conduction, any temperature could be obtained with the lowest possible consumption of energy, so that lagging is a most important point. The table on page 98 is rather interesting. It seems to show that in the case of these four installations the ratio between the number of kilowatts connected and the consumption is about the same, also the cost of maintenance is very low where the consumption is low. A table has been given showing the number of faults, but they are not given in detail. For instance "wiring faults" may be due to carelessness in fixing or to bad insulation. If the author would give further details they would be extremely useful. In the case of "B" in the table on page 99 the faults are very numerous, yet the upkeep is very little more than in the case of "A." It would also be extremely useful for propaganda purposes if some figures could be given for a gas installation. I notice that in the case of installation A an enormous amount of food is cooked, but the units per meal are exceptionally low. I should like to know whether this is due to the amount of food supplied per meal, or to more efficient apparatus. Mr. Thomas considers the load curves on page 100 to be unsatisfactory because there are very big gaps during the night; but station engineers might quote a special figure for units consumed during this period when water-heating might be carried on. There seems to be an exceptional peak on the summation curve between 11 a.m. and 1 p.m., and the maximum demand system of charging would not be very satisfactory on such a load. In most industrial districts the load goes off about this period, so that the total load curve will not be so peaky. I should like to endorse Mr. Thomas's remarks about the economy of cooking by electricity. Actual figures showing comparisons between electricity and gas cooking should be given, as there does not seem to be any important factor introduced to show less shrinkage when meat is cooked by electricity instead of by gas. In the London discussion an engineer connected with one of the railways asked whether electrical cooking could be applied to trains. I think the idea of using a petrol engine to drive an electric generator is impracticable, but one might have a system of storage batteries which could be charged at a terminus station, replaced at some convenient stopping place, and supplied with a little extra power by a generator on the train whilst running. My own feeling is that even this system is impracticable.

Mr. R. Weaving: I am pleased to note that the author places reliability first, as the absence of breakdown is more important than the consumption of a few more units. Most of the breakdowns in the past have no doubt been due to wiring faults and troubles between terminals and element wires. For three or four years I have watched wiring troubles, particularly in the smaller apparatus, but in the large ones such as have been described in the paper there is no doubt that the apparatus can be designed to allow of strip connections not less than $\frac{5}{8}$ inch wide being brought out direct to terminals. If the strip is on porcelain supports we get perfect insulation, but the porcelain must not be subject to a very high temperature. For instance, there is no need to have porcelain in the side of the oven. Strips can all be in the bottom of the oven away from heat. That removes one of the most awkward points of wiring. Wiring from the oven to the switchboard can be carried out on any ordinary system in the same way as the wiring of motors or lamps. I do not see why external wiring should give more trouble with cooking apparatus than with any other gear. There is an important point about the use of cast-iron clamps instead of wrought-iron clamps. A wrought-iron clamp scales badly with heat, the scale falls off, and eventually the clamp becomes loose from the element, with the result that the mica perishes and the element burns out. If cast-iron clamps are used these should be machined, and when the element is clamped between one of these and the

machined heating plate it makes a sound job. Something has been said with regard to the troubles due to the use of mica. The troubles are due not to mica but to using the wrong kind of mica. There is some mica which is specially adapted for electric cooking apparatus and it is not mica of the highest dielectric strength. Another thing is that mica under pressure withstands a high temperature, but if it is loose it will not, as it loses its tenuity and falls to pieces. If it is clamped up tight it remains good. I can remember a case in which three hot-plates were run at a cherry-red heat for over 4,000 hours. At the end of that time the elements were taken out and the mica was as good as new. These elements were very tightly clamped with cast-iron clamps. In another case the mica broke down in the course of 400 hours under the same conditions, but in this case the elements were clamped with wrought-iron clamps which became loose. After looking carefully into the question of lagging, it seems to me that it is hardly worth while to lag for more than 1 inch thickness; lagging for 2 inches adds but little to efficiency, costs a good deal more, and takes up useful space. The maintenance figures that the author gives are not what I should have expected from such installations, particularly in view of the emphasis he lays on reliability. Looking at the table on page 99, it seems to me there are too many wiring faults. I cannot imagine that the internal wiring arrangements were carried out on the solid system mentioned on the first page of the paper. In the case of installation B there are 130 faults, 27 of which are in the wiring and 20 in the oven. From my own experience there should have been no faults in either of these places. The oven elements properly designed should have an average life of over three years. The table on page 98 is interesting. It is about the first time that anything really definite has been given on that point, but I have always estimated the consumption of energy at 0·5 unit per meal per person. We have equipped a canteen where they supply meat and two vegetables for 8d. If the cost of electric cooking were very high a meal could not be provided for that sum. With regard to boiling water, I am inclined to agree that where there is a supply of steam available it ought to be employed, but if it is necessary to generate steam specially for the purpose, the question of capital cost must be considered. We have recently supplied an equipment in which not only the water for tea, etc., but a supply of washing-up water, cooking water, and water for baths and wash-bowls is provided, all heated electrically.

Mr. H. A. Ratcliff: The author refers to the water-heating problem, and in view of his recommendations with regard to coke and live steam it is apparent that he has not much confidence in the use of electricity for the purpose. Personally I have always considered that the electrical heating of water was not a commercial proposition. At any rate not with electricity costing more than ½d. per unit. When we get down to that figure the supply of hot water even in large quantities will be worth serious consideration. I have no doubt, in view of the author's extensive experience of the subject, that he could have told us very much more with regard to the good and bad points in the design and construction of electrical cooking apparatus, and it is therefore rather a pity that he has not done so, as the information would have been of interest to all of us and of very great value to manufacturers. Some of the apparatus one comes across gives the impression that the manufacturers are greatly in need of such information. The specifications of the several equipments seem to point very clearly to the passing of what may be called the "tin-box type" of cooker. That is all to the good, of course, but from the constant references in the paper to heavy-grade cast iron it almost appears as if manufacturers were going to the other extreme. Something between the two will probably afford the best solution ultimately, and the Americans appear to be working very much on these lines at the present time. In the list of advantages of electricity I observe that there is no reference to hygienic considerations. I should have thought that they constituted the chief advantage of electrical cooking apparatus; the ordinary naked-flame gas-oven is probably as unhygienic a device as it is possible to have, and there is no doubt that many of the ills of modern life are directly attributable to the extensive use of this type of oven. I am surprised that the author refers to the decreased loss of weight when meat is cooked electrically, as I was under the impression that that idea had been thoroughly exploded. Statements of that description have certainly not helped to advance the cause of electrical cooking. If there is actually a saving in weight it probably arises from a lack of ventilation, and that in itself is really a condemnation of the type of apparatus employed. With regard to the nature of the load curves, there are two aspects of the peak question. One is in connection with the load on the supply station, and the other with the load on the mains, and the effects are rather different. In most manufacturing districts the various works shut down at or about the same time and the employees invariably expect their dinner to be ready immediately after they cease work. That being the case, the cooking load is necessarily bound to clash with the power load. In the case of domestic cooking the conditions are somewhat different and will depend upon the neighbourhood, that is to say, whether the residential portions of the town are some distance or otherwise from the industrial and business districts. In winter time there will necessarily be a considerable clashing of the suburban cooking and lighting loads, but as a rule the effect on the mains will be of more consequence than the effect on the generating stations. The obvious remedy for this trouble is to provide ample copper in the distributors, and there is no doubt that in towns where exceptionally small distributors and service mains are by no means uncommon in the residential districts, the possibility of a large cooking load is not regarded by any means favourably.

Mr. H. Allcock: I recently formed the opinion that the design of electrical cooking apparatus, especially that of boiling plates, was now in the critical stage when the working voltage was an all-important factor, and I should like to have the author's ideas on that point. We all remember the time, for instance, when the metal-filament lamp was satisfactory up to 200 volts but was unreliable at 250 volts, and I suggest

that is the stage we are now passing through in the matter of boiling-plate design. Some plates I tried on a three-wire 250-volt × 250-volt system with the middle wire earthed had very short lives. One trouble appeared to be the development of hot spots, due either to faulty heat distribution or to the disintegration of the mica—in any case the heating element in the plate broke down to earth. Whatever the cause, the fact remained that the boiling plate was the most unreliable part of the equipment on trial, and the electric kitchen idea was condemned for the time being. Another great difficulty is the boiling-water supply. To come forward, as the author does, at this date and say that water can be boiled electrically if it is first nearly raised to boiling point by steam is a very damaging admission. In fish-frying I understand it is essential to bring the fat to a very high initial temperature, to plunge the fish into it, and to replace the loss of heat very rapidly. The electric fish fryer is handicapped because the rate of heating is less rapid than in the case of a gas-heated fryer. Water-boiling and fish-frying are thus in my opinion special features outside the economical scope of the "all electric" kitchen. Other speakers have dealt with the author's maintenance tables, but I should just like to refer to the excessive number of wiring faults; surely such troubles should be capable of complete removal if properly tackled. It is a disgrace that we should be asked to accept 21 wiring faults in any installation. Generally my feeling is that reliability is much more essential than any other factor when designing an electrical kitchen, and until those engaged in the business can succeed in obviating the many little breakdowns which, although possibly trivial, nevertheless put the apparatus out of commission until repaired, we shall make relatively slow progress in this particular field. The idea of an electrical kitchen has so much to commend it that I hope workers will not be discouraged by the handicaps to which I have referred.

Mr. H. R. Burnett: There are one or two questions which I should like to ask the author and which are of importance from the supply engineer's point of view. Curves showing the load in amperes are given on page 100; it is not, however, quite clear whether these curves represent the loads on two different days, or the load on the two sides of a three-wire system on the same day. Also the voltage of the supply is not stated.* [**Mr. Gillott:** The curves represent the total load on two days.] The matter is of considerable importance to the supply authority. It will be seen that in the case of installation A the maximum load is about 77 kw., or only about 31 per cent of the total loading of the kitchen. The consumption of 122,000 units in 10 months on this installation represents a load factor of about 21 per cent, which must be regarded as very satisfactory for canteen work. I wish the author had been able to give us a few figures showing the comparative cost of gas and electricity, for although electrical engineers may only regard the cost of electricity as a secondary consideration, there is no doubt that in order to obtain a large consumer for electrical cooking, we must be in a position to convince him that the total running cost of electricity will not exceed that of gas.

* Since added by the author.

With regard to hot-plates, I should like to know whether the author's experience has been entirely with the black type. They are no doubt satisfactory for canteen work where special utensils are provided, but my experience is that the ordinary domestic consumers will never be satisfied with this type of hot-plate, the invariable complaint against them being that they are too slow. The radiant hot-plate, on the other hand, gives great satisfaction. Although this type of plate was only introduced into Barrow a few months ago, it is now being used in very large numbers. I shall also be glad to know whether the author recommends the thermostatic control of ovens or other apparatus used in connection with canteen work. It appears to me that, if ovens used for certain purposes and hot cupboards were controlled in this manner, a considerable economy might be effected in the consumption of electricity.

Mr. H. D. Symons: In outlining the essential items for the adoption of electricity for cooking purposes in large kitchens, the author very rightly places reliability first, and from the slides that he has shown it is clear that a great deal of forethought has been given to the lay-out of the cooking plant from the point of view of convenience. As the result of the adoption of electricity in my own house for cooking and domestic purposes, I am convinced that this point is not sufficiently appreciated, and the table of the initial outlay on installations on page 99 and the units per meal of these installations shown on page 98 confirm the view that convenience is frequently to be considered before cost. As an instance of this, one has only to cite the almost universal adoption of the fountain pen by business men. Again, from the point of view of cost, the actual cost for energy is very small compared with the cost of the materials cooked; the prices of different foodstuffs vary so greatly that it is extremely difficult to arrive at any very definite idea as to what the ratio of the energy cost to the cost of the materials cooked is, but I should like to ask the author whether this point is ever taken into consideration in deciding whether electricity be adopted. With regard to the use of mica for the insulation of heating elements, referred to by other speakers, in my experience the softening or disintegration of the mica when subjected to high temperatures is due to the de-hydration of the moisture of crystallization, and those micas having the highest percentage of moisture of crystallization are the best for use in the manufacture of heating elements. Nevertheless, it is only a question of time before the best mica, when subjected to a temperature of 400° to 500° C. will become de-hydrated and finally soften and disintegrate, although even when this has occurred there need be no fear of breakdown provided due attention has been given to the design of the heating element. One of the next steps in the development of the heating element is, I believe, the production of a material the temperature coefficient of which shall not change in service, a research which the National Physical Laboratory is most competent to undertake. Mr. Thomas has referred to the fitting of cooking ovens with thermometers; I venture to think that only a very small proportion of the people

who now perform cooking operations understand the difference between the Centigrade and Fahrenheit scales, and the addition of the thermometer would therefore only be confusing. In my judgment, it is far better to rely on a time basis, since temperature and quantity of heat are always direct functions of the time.

Mr. J. D. Paton: Mr. Symons has raised a question in which I am interested, the question of the stability of alloys, and I have previously stated my ideas of the basis on which stability is obtained, i.e. the balanced relation of the constituents according to their (positive-negative) static coulomb capacity at the temperature at which the alloy is to be used. Suppose we have a refractory tube and we put hot metal in at one end and remove it at the other, also that during its passage a current of electricity is sent through the metal; as proved by Laval there will be a segregation of impurities to the outer zone, and if the stream of fluid metal is intercepted and extracted at the centre, a purer metal will be found than at the exterior of the remaining annulus. All alloys are subject to electro-thermic or Chatelier effects, and the reciprocal of the flowing current effect is simply a magnified Chatelier influence. The recent research work of Dr. Ezer Griffiths at the National Physical Laboratory bears out my view. In my investigations in the United States on the purification of steel I followed Laval's work, where a rod of hot metal through which he sent a heavy current was under observation. In the centre of this rod he had absolutely pure iron and on the outside he got scum due to the action of the current producing a segregation of what I call the unbalanced element in alloys. In alloys I hold that their relative resistance to heat transference is a function of the relation of the positive and negative characteristics of the constituents. If I take a platinum-iridium 2 per cent wire and a platinum-iridium 10 per cent wire and join them as a thermo-couple they are relatively stable up to certain temperatures in composition and electro-thermic value, but at certain critical heats there is a transfusion of the 10 per cent iridium into the 2 per cent wire until a balance of 5 per cent and 7 per cent is reached, and this again remains stable up to a further critical point. If I continue to heat resistance wires by electrical current I have disintegration, and in examining that segregate (where its presence was primarily necessary for a high-resistance material) we shall find an unbalanced element of metal; and if we continue, our final alloy will have a minimum resistance, as defined by the alloy whose static natural charge capacity produces a neutral condition. That is, if we have a certain excess of chromium to the amount of nickel which was "natural" and giving what is actually solution, we have other portions which do not pass into combination with that element but are intimately mixed. If we start to heat by electrical current they become segregated, and the Chatelier effect drops. From microstructures which I have had to examine, of steel wires electrically welded and showing the various effects at different zones radially displaced from the centre of the weld, I have further evidence to confirm my ideas.

Mr. H. T. Wilkinson: Those who dined at the Club to-night had a dinner cooked by gas. This installation was put in originally because capital expenditure is an important matter when starting a club; also the Gas Committee made a tempting offer of free apparatus. Now that the membership is so much increased an extension to the cooking apparatus is necessary to ensure quick service. We have decided to install the following apparatus, all electrical:—a hot cupboard, an oven and three boiling plates, and a grill. Although the capital cost was heavy we were quite convinced that it was justified, for the following reasons. The additional hot cupboard was necessary to ensure quick service. We have not found the gas hot-cupboard satisfactory. The gas burners gave trouble. The heat was unequal and dried up the food. We found the gas grill unsatisfactory, as it is necessary to wait about 20 minutes before one can get a chop or steak. It takes 10 minutes for the grill to heat up before it cooks at all. The additional oven and boiling plates were considered to be desirable additions to cope with the increased service necessary. In addition, the installation of more gas apparatus would have involved another large iron hood, which would have been expensive and awkward to fix in the centre of the kitchen to get the fumes away. We have already had to install a fan in the kitchen to exhaust the fumes, as the staff suffered in health. With regard to the running cost, we came to the conclusion that the cost will be approximately the same as with gas, more especially considering the high cost of meat and the possibility of reducing the loss in weight. I have some figures as to the cost of gas-cooking, but they are only approximate and include the cost of heating water, of which a large quantity is used in washing up and in the lavatories. The cost of the gas is about 0·9d. per meal served. At the mill mentioned by the author we were told that the cost of current was about 10 per cent of the cost of food, the totals being for one period £4 and £40 respectively. The food, of course, was not of an expensive kind. In that mill the advantages of electricity for a quick service were well demonstrated. They started carving one hour before dinner time, put the portions on plates in a hot cupboard, and served them over the top of it, which acts as a counter, within 10 minutes, the food being in as good condition as when it went in.

Mr. A. S. Barnard: If the cost of electricity used in cooking is calculated as a proportion of the total cost of the meal served, it seems to me that any threatened rise in tariffs loses its importance by comparison with the enormous increase that is taking place in the price of the raw materials, which really controls the cost of the meal. At a works at Clifton-junction, just outside Manchester, there is a 20-kw. electrical kitchen catering for 80 to 100 people every day. We supply meals from this canteen to men at 9d. per meal and to women at 8d. The meals consist of hot meat, two vegetables, and a milk pudding, or something similar. The electricity for cooking these dinners averages ½ unit per meal, and assuming a price of 1d. per unit for the current, this means that the cost of electricity is about 6 per cent of the cost of the meal. It seems probable that the cost of the raw materials in the food

will increase at a greater rate than the cost of the electricity; and if this be so, the cost of electricity becomes even less important.

Mr. W. A. Gillott (*in reply*): The majority of the speakers have shown a tendency to discuss the electrical heating of water in large quantities, and they all come to the same conclusion that it should not be attempted. Upon referring to the paper it will be noticed that I recommended, on account of its low running cost, the installation of a coke boiler, or, if available, live steam to deal with this problem. I therefore fail to see why they should labour the point on cost alone. Owing to local conditions it may not be possible to install a coke boiler; we must therefore decide whether to use electricity or gas, and here again the local conditions would largely govern our decision. With electricity at $\frac{3}{4}$d. per unit or under, and gas at 2s. 8d. per 1,000 cubic feet or over, I would certainly install electrical apparatus as being the better proposition taking into consideration running and maintenance costs, convenience, and fire risks. In supplying electrical heating apparatus, I would arrange to fix the tank as near as possible to the point of use, and thoroughly lag the tank and pipes; the heaters would be designed for long-hour use and controlled by a thermostat, and a time switch would be provided to cut off the supply during the station peak.

Mr. Thomas seems to fear an increase in price of electricity when electrical cooking becomes more general. Is that not one of the factors that would have a greater tendency to keep the price low owing to the general improvement of the station load? For the moment let us refer to the power load. In the early days when lighting was the mainstay, low rates were quoted to induce consumers to use motors. What is the result? In the majority of cases the station peak is now caused by the power load, and have the rates gone up? On the contrary, they have come down, and I venture to think the same will apply to electrical cooking. To me, it will be a happy day when the station peak is caused by cooking apparatus; it will then give central-station sales engineers an opportunity of demonstrating their grit in obtaining new business to fill up the gaps between cooking peaks.

The three essential qualifications for good kitchen practice, i.e. reliability, quick service, and efficiency, are, I agree, all of great importance. I consider reliability to be *the* most important, as without reliability the others lose their significance.

The washing-up arrangements shown in Fig. 3 are a distinct improvement upon the machine described by Mr. Thomas. I think he overlooks an important item when he refers to the dirty plates handled when food is being served. This kitchen is in a canteen where all meals are served first and no soiled plates are collected until the diners have finished their meal. The plates, etc., are collected and placed in wire frames (the crockery itself not being handled any more until it contains food for the next meal) in which they are washed, sterilized, dried, polished, and stacked. This arrangement permits a smaller stock of crockery owing to its rapid handling, and considerably economizes in labour and breakages. The "washers-up" are inside the central wash-up and do not interfere with the kitchen staff handling the food.

I cannot agree with Mr. Thomas in his contention regarding self-contained apparatus. It is of course understood that I do not suggest that every small pot or saucepan should have its own elements; these are heated on the boiling-table. The self-contained apparatus in the schedule could not, in my opinion, be reduced if good results in the kitchen are desired. The question of meat shrinkage is really a secondary consideration, and is not put forward so much now as a reason why electrical cooking apparatus should be used; so many other advantages are secured that this need not now be mentioned to secure business. I do not agree, however, with his figure of 3 per cent only in favour of electrical cooking. I have carried out tests where the shrinkage has been only 5 per cent and have had as much as 57 per cent shrinkage with a coal-fired oven.

Mr. Jepson refers to trouble due to balancing. I agree that this is difficult on three-wire networks and three-phase circuits, and I would refer him to my reply to the London discussion on this subject (page 109). I have also dealt in that reply with wiring faults and the comparative running costs of electricity and gas and the comparison of work done in installations A and B.

Mr. Weaving's experience with the practice in large kitchens is comparable with my own, as he agrees with me on the subject of reliability, solid type connections, cast-iron clamps, etc. I should like to enlighten him on the subject of wiring faults; these were mostly in the flexible metallic tubes. This is one of the weak links which I am anxious to remove, and by the adoption of solid type connections on certain apparatus these faults have been overcome, and will more or less disappear in the future.

Mr. Ratcliff wishes I had gone more into the question of the design of the apparatus. While agreeing that I could have dealt with this question, I purposely refrained from going deeply into the subject as it would have entailed a very long paper. I hope, however, my replies to the various speakers will give him some of the information he desires. With reference to the ventilation of ovens, it is not necessary to provide for a rapid ventilation with an electric oven, as no combustion takes place, the only ventilation necessary being to carry off the steam from cooking, which is provided by a small hit-and-miss ventilator. In Newcastle we do not find that the cooking load clashes with the power load. Regarding the "domestic" load, I would refer him to my previous set of curves (*Journal I.E.E.*, 1915, vol. 53, pages 46 and 47). I agree with him that the effect of the cooking load is mostly felt on the distributors, and these will require careful consideration in the future.

Mr. Allcock raises an interesting subject as to the life of an element when working on a 200-volt circuit and on a 250-volt circuit. A 200-volt element naturally is mechanically stronger than a 250-volt one, as a thicker wire or ribbon is used, especially so in hot-plates of equal areas, as one cannot use a larger element on the higher voltage. His troubles with hot spots are no doubt due to uneven pressure on the element; it would be interesting to know if the pressure plates were

of wrought or cast iron—if the former, he will surely get hot spots after a few weeks' run. His troubles with mica on hot-plate elements may have been caused by this or by concentration of heat, i.e. the loading in watts per square inch may have been too high. With self-contained vessels, I have not experienced any difficulty in fish-frying; the fryers mentioned in the schedules are in constant use and satisfactorily perform the work at the respective installations. No doubt the cause of his trouble was due to too small a loading for the size of utensil employed.

In reply to Mr. Burnett, the load curves represent amperes at 240 volts and give the load on two separate days. I have tested both the closed and open or radiant type of hot-plates. They both have their advantages, the closed plate having the advantages of longer life, more robust construction, and better facilities for heat regulation. The open or radiant type is only better for the first "boil." To provide heat regulation one must either use a duplicate winding or employ a thin wire, which results in a short life. I do not think much saving would be effected by the use of thermostatic control in ovens. I would not advocate their use for this work, but they can be employed with advantage in water-boiling and soup-making in large quantities.

Mr. Symons has apparently arrived at the conclusion that the convenience of electrical cooking is to be taken into consideration when the consumer pays his electricity bill. This is not the case and I again repeat that, on the score of running cost alone, electricity is cheaper than gas, on the basis of $\frac{3}{4}$d. per unit and 2s. per 1,000 cubic feet. When the convenience and incidental advantages and savings are taken into account, the economy is much greater. I would refer Mr. Symons to my replies to other speakers on the comparison of food and energy costs. Regarding mica for element formers, it is true that there are different qualities of mica. If used in places such as ovens and grills, where they are not subjected to mechanical pressure, extreme care must be taken to ensure that they are not over-run, or they will quickly disintegrate; and for this reason I consider fireclay or similar material to be more suitable for grills of the restaurant type. I agree with Mr. Symons's views in regard to the use of thermometers for ovens.

Mr. Paton refers to an interesting subject, the stability of alloys and the methods of separating impurities in metals, but as this subject is not dealt with in the paper, I must ask him to excuse me in not replying.

Mr. Wilkinson's remarks are extremely valuable. They indicate, first, how far gas companies will go to secure business (by giving the apparatus free), which is ample proof that they anticipate a strong competitor in electrical cooking; and secondly, that gas for cooking has many disadvantages. His detailed remarks on the behaviour of the gas apparatus are no doubt being experienced by many other users. I will not labour the point, as these statements coming from a user carry more weight than from an advocate of electrical cooking apparatus. With regard to running costs, his figure of 0·9d. per meal served cannot be criticized in detail, as all water for washing up and domestic purposes is included. From what I saw of the plant in the Club kitchen and the general hot-water arrangements, I do not think the gas department can claim low running costs in this instance. Both Mr. Wilkinson and Mr. Barnard compare the cost of cooking food with the cost of the food itself. I do not think this is a reliable basis to adopt, as the cost of food is continually varying. I consider the number of units consumed per meal to be the most satisfactory basis, unless one is cooking a large quantity of one class of food such as meat or bread, when it could be expressed as so many pounds of food per unit.

Yorkshire Local Section, 18 December, 1917.

Mr. J. Shepherd: With regard to small kitchens, I consider electricity to be in every way suitable for all operations which the cook is called upon to undertake, but the title of the paper indicates the application of electricity for large kitchens and in my opinion electricity is not in every case suitable for large-scale kitchen purposes. I consider, from the point of view of heat economy, convenience, and reliability, that electricity is eminently suitable for roasting-ovens, baking-ovens, grilling, or toasting, but when the requirements are the warming of very large hot-plates, large hot cupboards, boiling considerable quantities of water, or making large stews, electricity is not so economical as steam. I am of course assuming that in the application to large kitchens, steam is always available for other purposes besides cooking. We must not forget that for every therm obtained by electric heating, at least nine or ten therms must be raised on the boiler grates, whereas with steam not more than two therms are necessary. The difficulty outlined is exactly the one already experienced with electric heating, namely, its inadequacy to provide requisite amounts of domestic hot water at commercial prices. Again, looking at the question in a commercial spirit, I am afraid it is impossible to construct large hot cupboards and large stewpans as economically when heated by electricity as by steam. The outside cases are roughly the same for similar pieces of plant, and the provision of steam jackets or steam coils is, I consider, cheaper than the equivalent of electric elements with their insulation, wiring, and switches. These remarks must, however, be taken as applying solely to large pieces of apparatus, which we find only in large kitchens where cooking is conducted on a large scale. The division of plant above indicated between electrically heated and steam-heated is one I recently adopted in the canteen arrangements of a large factory employing some 15,000 hands with night and day shifts. Although the plant was worked practically continuously throughout the week, I am glad to say that little or no trouble of any kind was experienced although the cooks had had no previous experience with electrical apparatus.

Mr. T. Roles: In view of the fact that the development of electrical cooking, at any rate as regards large

apparatus, has been but small in Bradford during the past few years owing to shortage of plant at our generating works and the time of the staff being fully engaged on other matters of more immediate importance, I am very pleased indeed to have learned from the paper that electrical cooking has of late made such wonderful strides. Four or five years ago advocates of electrical cooking were like voices crying in the wilderness, and therefore it is satisfactory to find that such developments have taken place. It is suggested in the paper that the future depends upon close co-operation and exchange of ideas between supply authorities and manufacturers, and with this I heartily agree. I would say that at one time there was a small association which used to meet specially to discuss these matters. At its round table conferences about once a quarter some very useful experiences were related, and I think that both the manufacturers and those who used the apparatus got much benefit from the opinions expressed. The author stated that reliability, quick service, and efficiency were the great considerations. He did not mention cost, and I admit that cost is not everything, still when one was quoting for a large installation unless one had the silvery tongue of the very experienced salesman it was very difficult to get over the objection that under ordinary conditions electrical apparatus usually costs considerably more than other apparatus. The fact that there are now a number of large installations in use has been instanced by the author, and seeing that the results obtained in connection with such installations are so satisfactory it should in the future be considerably easier to induce persons to adopt electrical cooking. I consider the author to be right in advocating that the services should be run in duplicate to the various floors, and that there should be a fuse upon each piece of apparatus. Domestic cooking in the old days suffered very much from the fact that complete electric ranges usually had only one fuse, and on this blowing as a result of one element becoming faulty, the whole of the food being cooked was often spoiled. The author states that the wiring may be run in solid-drawn tubes direct from the hot-plate case to the terminal box. It would be rather interesting to see what sort of connection he makes between the apparatus and the box so that the apparatus can be easily taken away for cleaning. Plate and dish warming is a matter of considerable importance, especially in restaurants. In a large installation in Bradford it was found that there was not nearly sufficient hot-cupboard space, and a whole meal was spoiled by the fact that the plates were cold and also the food. Apparently the author has throughout used the black hot-plate. Some years ago many engineers considered it very necessary to develop heaters used at a red heat so that the cook could see that the hot-plate was switched on without such a lot of indicating gear as has been shown on the screen. With such heaters also it was not so necessary to ensure that the bottoms of utensils were perfectly flat and smooth. I have tried a number of these heaters, but have not found them altogether satisfactory; they lasted for various periods, usually from a fortnight to three months if they were in anything like continuous use. I should like to know whether the whole of the installations mentioned by the author are connected to alternating-current systems, or whether some are supplied from alternating-current and some from direct-current systems; also whether he has any records showing that apparatus breaks down sooner with alternating current than with direct current, as I have had reason to believe that this is the case. It is very necessary that the actual requirements in connection with any installation shall be carefully ascertained if the apparatus supplied is to be such as will best meet those requirements. A few years ago I found that a number of the manufacturers knew very little of such requirements, and I doubt whether the users knew any more, or indeed as much. It is very difficult to get the customer to state exactly what he does want, especially in regard to a new type of apparatus. It is necessary that we should utilize experience to the full, and therefore this paper is likely to prove most useful. In the description of certain apparatus the author mentions that the sides are lined with asbestos; I should like to know why that was used, as although asbestos is fireproof it is not a good heat insulator, at any rate compared with slag wool. The load curves are very interesting. The author told me before the meeting that he wished it had been possible to obtain the load curve of the supply system to show how the load curve of the cooking installations affected the general load curve of the supply. It would have been most useful if he could have done so, because one does want to get some idea of the effect that the cooking load is going to have on the general load of supply systems—whether it is going to fill up the gaps or to accentuate the peaks. I should have liked to have seen a curve showing in the case of the munitions-works installation the load on the works and also the load taken by the kitchen, for that would have given us a very good idea of the relation between factory and cooking loads. I think the paper well worth careful perusal, if only for the purpose of obtaining an idea of the strides which have been made by manufacturers in producing electrical apparatus for cooking purposes.

Mr. W. M. Selvey: The selection of this paper shows how ill-founded is the accusation sometimes brought against the Institution that it is out of touch with commercial subjects. I think the technical matter of the paper is not more than about 15 or 20 per cent of its total, and the rest is purely commercial. That is excellent because, though we should always have a very large proportion of highly technical papers from designers, it shows how such an apparently small matter from the theoretical point of view may turn out to be one of the most important subjects which supply engineers may yet have to consider. The number of kilowatts per person for cooking may turn out to be a very considerable proportion of the total demand per person for all purposes. It rather leads to the idea that there must be some very exceptional circumstances in the North, because in other districts all such applications for domestic purposes have had to be turned down for a long time. The question is whether the domestic load to-day will not have to be reduced. The thing any electrical engineer looks at in regard to the nature of some new load is: how

does it dovetail in with the other load? If it appears that the principal domestic consumption occurs practically at the same time as the biggest expenditure for other forms of human industry, there is no dovetailing but, rather, overlapping. If the curves given from 10 a.m. to noon are typical, it shows that people in the mass prepare for the principal meal at midday. Between 10 a.m. and noon is also the heaviest load on the power system. Again there is the sub-peak at tea-time which occurs almost identically with that worst peak at the worst time of the year when we get lighting overlapping the power load. There is the more serious curve between 8 p.m. and 6 a.m. When we think of it, it is rather surprising, considering that it is quite easy for the ordinary housewife to bake bread at short notice in the ordinary coal-fire oven, that these large installations have not begun to bake during the night. I think nearly all the bakers at the present time bake the bread at night and therefore there is no new labour practice to be introduced. It could be arranged that cooking should be done in shifts, which would make all the difference. Bread will continue to be the bulk of the food consumed by mankind, and that bulk will probably take just as much cooking as meat. There is very little in the paper about the technical details, but I gather from the author that these have rather become secondary matters, having been so much improved now that they do not bulk in discussions like they did in the early days. We used to hear about terminals which were burnt out and so on, and the way in which these troubles have been got over is a most important matter for the engineers. To the general public and the people to whom we are selling, the figures given in the paper are of considerable importance. It is not fair to ask too much in the way of these details, but probably in his reply the author can give us one or two hints which would be of interest to engineers from the purely technical point of view. Those of us who have endeavoured to follow Mr. H. G. Wells will have noticed that he deals with the tendency towards communal living. If we are to have economy of labour, and heat and effort and apparatus, and the rest, as he points out, we shall be forced to some form of living, eating, and playing together. The fact that restaurants and hotels are gradually adopting electric cooking suggests that this is one of these particular methods of doing things which fits most excellently into that system. I should gather that when cooking is done on this scale, like many other things the cost of the power is not a factor which is of the first importance. That is the impression which the author has succeeded in giving me.

Mr. C. E. Allsopp: Many difficulties present themselves in equipping a large kitchen, and even the manufacturers of the electrical apparatus in many cases have failed to realize this; this paper will therefore be of very great assistance to those who are taking up the question of large electric cooking installations. In deciding upon the apparatus for a large kitchen it should be realized that hot cupboards and fish fryers large enough for ordinary café or restaurant work, for 500 diners during a period of, say, two hours, will be found to be quite inadequate for dealing with 500 diners at one sitting where a six-course menu would require at least 2,000 plates to be heated prior to serving. This is a point that very often appears insignificant at first sight but presents considerable difficulties if ample hot cupboard room for plates has not been provided, in addition to the space required to accommodate joints, etc., prior to carving. The servery and the accommodation for lifts and general transit from the kitchen to the dining table should also have the closest attention of those interested in the matter of kitchen equipment. I should like to ask the author what his experience has been in connection with the use of thermometers on cooking ovens and also indicating lamps, and whether in his opinion they are a success or not. Several types of indicators have been put on the market, some of which are in the form of a resistance with a "pea" lamp of low voltage across the wire, which glows with varying intensity according to the current passing through the resistance wire, also a nichrome wire giving a varying glowing effect behind a lens and acting incidentally as a fuse, and the carbon lamp behind red glass. In my opinion these all prove unsatisfactory after continued use, and could with little cost and greater reliability be replaced by fixing series ammeters in circuit with the larger pieces of apparatus; the reading of the ammeters would give a clearer indication to the chef as to the amount of current that was passing than any of the above-mentioned devices. Will the author inform us as to what his experience has been regarding pin contacts on hob hot-plates and inside oven elements. The success of the Canadian and American-made cooking apparatus has been found to be largely due to the fact that they are made for lower pressures than are generally found in this country, and it would be interesting to hear whether the author is of the opinion that the success of apparatus in this country is handicapped to any large degree by the higher pressures in vogue here. Recently a manufacturer of a very successful Canadian oven was requested to quote for an oven suitable for a pressure of 230 volts, and he declined to do so on the score that he could not guarantee it at much higher pressure than 120 volts.

Mr. H. W. Walker: In several of the cooking installations I have seen, it has occurred to me that the ventilation of the room has not been given the attention necessary. If the question of ventilation had been considered to a greater extent a number of premature element faults caused by condensed steam would have been eliminated. In regard to the cooking, I have had arguments with gas engineers on several occasions with reference to the actual loss on meats in cooking, and have taken numerous tests, but I have not as yet been able to come to a satisfactory conclusion. I have read periodicals, textbooks, and manufacturers' literature in which they always claim that there is a 15 per cent saving in the electrical cooking of meat in comparison with other forms of heating, and this is a very serious item at the present time in view of to-day's price of meat. I am of the opinion that if an intense heat of any form be applied to meat at first, the outer cells are sealed and therein lies the secret of economy in the actual amount of meat saved. I

think, however, that this effect can be produced by any kind of heat, and not by electrical heating only.

Mr. W. B. Woodhouse: The discussion seems to have turned on the disadvantages of electrical cooking in large kitchens. The author tells us that, owing to the diversified apparatus in use, electrical cooking is now a sound commercial proposition. I have not the slightest doubt that this is so, and from my own experience I find it compares very favourably with gas or steam. In considering the cost it must be remembered that 1,000 cubic feet of gas contain approximately 1/60th of the heat of a ton of coal, and, if coal is £1 per ton, that 1,000 feet ought to be got for 1d. Actually it would be necessary to pay at least 3s. for 1,000 cubic feet, or 9 times as much as it is worth in heat value. This is because it is convenient to use the heat in the form of gas. The convenience of electrical cooking is far ahead of that of gas, and the control is even more satisfactory. In regard to steam heating, this is satisfactory if the use is steady and continuous; but on looking at the cooking load-curves it will be seen that the demand is very far from constant and for the greater part of the day there will be a heavy loss in the steam heat, a stand-by loss. When this is taken into account it is not likely that the scheme which the author has given us particulars of will be improved on. With regard to load factor and diversity, the tendency more and more is for the lighting load to become unimportant in public supply. Lighting is already less than 5 per cent of the total in some cases. There is also to be considered the tendency on the part of factories to work shorter hours and for the midday meal to be reduced, so that everything tends towards the cooking load fitting in very well with the general power supply.

Mr. A. R. Chaytor: I should like to ask the author whether he has gone fully into the question of taking a supply off a three-wire system direct to the apparatus for use on separate elements in the one piece of apparatus, as I am of the opinion that it is not permissible under the Board of Trade Regulation A 1 without special sanction. Still I consider that it is time the Board of Trade Regulations were brought up to the level of modern requirements in this matter, for, if it is permissible to have motors, arc lamps in series, and incandescent lamps in series off a medium-pressure supply, on the understanding that the wiring is carried out in metal tubing with proper switches and cut-outs (which, by the way, is in nowise different from standard practice in the majority of installations), I cannot see why fixed heating units should not be given the same freedom, with its consequent facility of development. There is just one other point I should like to mention. Several of the previous speakers have been advocating various expedients for judging the temperature of the ovens. For this purpose I should like to suggest the fitting of a glass door to the oven, as is done in many modern ovens (both fire and gas-heated) so that the cook can have the advantage of seeing the food actually in the process of cooking, without the necessity of opening the oven door and thereby losing heat.

Mr. W. A. Gillott (*in reply*): To a certain extent I am in agreement with Mr. Shepherd in the use of steam and electricity in large kitchens. As I pointed out when showing the lantern slides, steam is used at installation A for the large pudding steamer and stock pots, also in Fig. 3 steam is used for similar duties, because steam is available and is used for other purposes. It is not possible in every case to produce steam owing to local conditions, and unless a kitchen is to provide meals for night and day shifts, such as a canteen which he mentions, or an hotel working from, say, 7 a.m. to 12 midnight, I would not advocate installing a boiler. The hot water for washing up is dealt with in connection with the usual domestic supply; therefore in these instances they do not come under steam applications. It would, for instance, be an extravagance to provide a boiler for a kitchen performing duties such as those at installation B, where steam would only be used for the midday meal. The labour and maintenance costs and heat losses would be out of all proportion to the service rendered. I cannot agree with Mr. Shepherd as to the cost of electrical and steam hot cupboards. I have before me quotations for a number of 10-ft. hot cupboards for steam and electricity; the electrical ones are actually cheaper than the steam, including the switches and valves in each case.

Mr. Roles refers to the need of an experienced engineer salesman, in which I entirely agree. It is not, however, in the mere selling of the apparatus that station engineers must exercise their ability, but in the more practical side of designing an efficient lay-out and understanding the kitchen requirements, so that they can, without hesitation, definitely state to their clients what results will be secured by using electrical cooking apparatus. One must not expect the caterer to say what gear he requires; it should be sufficient for him to state the work he desires to perform, and leave the plant to the engineer. The installations described are working on both alternating and direct-current systems and I have not found any marked increase in the faults on alternating-current systems as against direct-current systems. The asbestos lining referred to is employed in the sides of hot cupboards and is of soft asbestos sheet approximately $\frac{1}{4}$ inch thick; it is quite satisfactory for this class of work. I would refer Mr. Roles to my replies to other speakers on the subject of the load curves. I hope to have an opportunity of referring to these later.

I am pleased that Mr. Selvey appreciates the commercial spirit of the paper; owing to the view of some station engineers on electrical cooking apparatus, I felt it was necessary to bring out this feature. There are no exceptional circumstances in Newcastle to cause these installations to be erected; it is merely a result of the application of the commercial spirit referred to. Regarding the load curves, I would refer Mr. Selvey to my replies to the discussions in London and before other Local Sections. I agree that considerable work can be carried out between 8 p.m. and 6 a.m. We have not yet, however, connected up any bakeries for electrical baking, but this will surely be done when Government restrictions are removed.

The difficulties of equipping kitchens mentioned by

Mr. Allsopp can be summed up in one word—experience. Should one be uncertain as to what apparatus to supply, expert advice should be obtained, or failing that the subject should be discussed with the chef. I have not found thermometers to be of much assistance; the type usually supplied is unreliable, and to provide a reliable pyrometer would be an expensive addition. I have found the ordinary 5 candle-power carbon lamp to answer quite well as an indicator. I recommend that the cases surrounding the lamp be well ventilated. The cost of supplying ammeters on each circuit would be too costly to adopt generally, although one could be put in circuit on the main, where the tariff is on a maximum-demand basis, to indicate the load. My experience with pin contacts has not been satisfactory; consequently they have been discarded. I agree that heating elements are mechanically stronger for a 120-volt circuit, but for a manufacturer to refuse to make apparatus for 230 volts is, in my opinion, an admission of inexperience.

I cannot say I have found many element faults due to steam in the oven as stated by Mr. Walker. I have, however, seen the leads go to "earth" due to moisture, but this is now eliminated by providing suitable connections and terminals so that the wiring is kept away from excessive heat or moisture. I refer Mr Walker to my previous replies on meat shrinkage. I agree with him that the application of high temperature, i.e. 340° F., seals the outer cells of the meat and retards the escape of juice, but this high temperature must be lowered during cooking to prevent the outside portion of the joint becoming hard and dry, otherwise the advantage of low shrinkage is lost. The electric oven is not freely ventilated, and possessing the facility of absolute heat regulation assists in the conservation of waste.

Mr. Woodhouse's remarks are an acquisition to the paper, as they not only demonstrate the advantage of electrical heat control, but point out the necessity for a practically constant load if steam is to be used on the score of economy. My views of the application of steam are stated in the reply to Mr. Shepherd. I agree with Mr. Woodhouse on the question of curves, and the tendency of the cooking load to fit in with the power load.

As Mr. Chaytor points out, it is necessary to obtain the Board of Trade permission to connect up cooking apparatus on pressures above 250 volts. I have not fitted any apparatus with a three-wire or a three-phase supply direct to the heating elements, and unless a low pressure of not more than 200 volts between outers were available, it would be difficult to obtain fine heat regulation. There are many electrical ovens with glass doors as advocated by Mr. Chaytor.

DISCUSSION ON "GAS FIRING BOILERS." *

BIRMINGHAM LOCAL SECTION, 5 DECEMBER, 1917.

Mr. H. E. Midgley: I am of the opinion that the tabulated results given in the paper will be of the greatest value to managers of blast-furnace plants and others having available sources of gas, as the tables are in a practical form easily understood. It will be very much easier for some of us who carry out first negotiations for the installation of power plants to obtain more definite premises of the conditions in relation to estimated steam-raising facilities by using the tables contained as agreed data basis. I should like to ask the author whether in his calculations he has assumed the moisture contained in the gas to be steam or water. My opinion is that the moisture contained in the gas is steam, and that therefore it is unnecessary for the latent heat to be added in the efficiency calculation. I do not fully agree with the statement in the second column on page 62 that: (1) the gas must be clean, and that (2) it must be dry; or with the author's note that the latter requirement is even more important than the former. I would modify this statement as follows: (1) The gas should be dry. (2) The gas must be clean, and this is even more important than being dry. My company have had practical experience with blast-furnace gases under most systems of cleaning. In a particular instance where the blast-furnace gas was efficiently cleaned by Fraser & Chalmers' Halberg Beth process it was found that the gas would not burn. The fault was located in a leaky valve, which allowed some 5 per cent of dirty gas to be by-passed and mixed with the clean gas. It may be mentioned that the clean gas was cleaned to a condition approximating to 0·003 gramme per cubic metre. The non-burning was, according to generally accepted theories, attributed to moisture, and it was claimed that the moisture put into the gas by the initial cooling process was causing the non-burning of the gas. When the leaky valve was rectified the gas burned perfectly, although at the same time all the sprays possible were turned into the pre-cooling chamber, and the whole supply of gas was completely saturated with moisture. The gas in this instance entered the boilers at about 70° C. Another instance was where gas-fired boilers taking gas direct from blast furnaces working with calcined ores—the gases therefore containing no more moisture than is taken up from the coke, etc.—have to be stoked with coal owing to the failure of the dirty gas to burn, the analysis showing little moisture but impurities, especially potash, to a marked degree. The conclusion

* Paper by Mr. T. M. Hunter (see page 57).

arrived at was that blast-furnace gas containing even small percentages of potash or other material which is in so fine a state that it is impossible for a wet cleaning process completely to remove the same will burn badly, owing to this small percentage of dirt being carried over, and that if this dirt is removed the gas will burn perfectly although the same may be completely saturated with moisture. In connection with gas measurement, referred to on page 69, I remember considerable experiments being carried out with complete apparatus at Erith, when air-measuring apparatus designed by Mr. J. L. Hodgson of Messrs. Kent was completely developed, and after very exhaustive experiments was installed in South Africa in connection with the Rand air power scheme, giving results of extraordinary accuracy, the volume registered by the consumers' smaller meters checking with the main air meters within small limits. These air meters are designed to correct automatically for variations of pressure, temperature, and to read accurately within a wide range of volume. I believe that the installation of accurate meters for measuring the gas will help to remove many doubts now existing owing to the inability to measure accurately the flow of gas burning under boilers.

Mr. R. L. Goold : In reading the paper, the author added a remark upon flame temperature, and emphasized the importance of minimizing the excess of air. The admitted air, even when pre-heated, is, I assume, at a temperature of about 100°–200° C. The excess air has to be raised to the heat of the burner—a temperature, I assume, of about 1,200°–1,500° C. The consequent reduction of calorific intensity is obvious. We have to operate between this evil and the evil of unburnt gases in the stack. It is pertinent to remember that these unburnt gases in the stack probably consist largely of combustible gases which have been manufactured in the flame, as distinguished from gases which have escaped from the burner. The combustion of a hydro-carbon involves an interesting succession of processes. We see them manifested in a deep incandescent coal-fire. If there is a generous supply of oxygen at the base of the fire, part of the carbon burns to form carbon dioxide. In ascending within the interior of the incandescent coal through a region in which an inadequate supply of oxygen prevails, the inert dioxide is converted into the combustible monoxide, which is seen to burn upon the surface of the incandescent coal with a lambent blue flame. In a non-Bunsen gas flame, combustible gases are generated in the flame. Almost every flame is hollow ; the interior is unburnt gas from the burner. In the lower part of the flame, however, a portion of the gas burns with an insufficient supply of oxygen ; carbon monoxide is produced and hydrogen liberated. In the case of methane, the equation is :

$$CH_4+O_2=2H_2O+C=CO+H_2+H_2O\ ;$$

and with ethylene,

$$C_2H_4+O_2=2H_2O+2C=2CO+2H_2.$$

We recognize the existence of these regenerated gases when utilizing the reducing blow-pipe flame. The gases which are regenerated have a high temperature, and actively extract oxygen from the material towards which they are directed by the blow-pipe. In a Bunsen burner, this process of regeneration is augmented. Admixed with the gas in the hollow interior of the flame is a proportion of air insufficient for complete combustion, but sufficient to promote this process of regeneration. With a flame burning in an unlimited atmosphere, substantially all of the regenerated gases ultimately burn in the upper or outer part of the flame. In a steam boiler, however, the conditions are severe and difficult. It is conceivable that the wetted surface of the boiler may be the means of so reducing the temperature in a region in which the regenerated gases are liberated that they escape combustion. The importance of thoroughly mixing the air is emphasized in the paper ; this mixing of the air with the gas is, however, a matter of the greatest difficulty, and the regenerated gases may escape combustion on this account also. My attempt to analyse the process of combustion is therefore submitted as a basis for an inquiry whether the desideratum of substantially complete combustion with a minimum of excess air could be more nearly attained by a gas-fired boiler the design of which is founded *inter alia* upon a recognition of the existence of combustible gases generated in the flame.

Mr. A. G. Engholm : I do not see that the author has given us any definite information concerning the cost of gas-firing boilers, and also whether it is likely to pay large works or electric light undertakings to install special plant for producing Mond gas or similar gas for that purpose. So far as I am aware it does not pay to put down a gas plant to recover the various by-products unless the plant can deal with, say, 200 to 300 tons of coal per day. For the satisfactory working of such a plant it is necessary to have a fully trained engineering chemist who has at his command the most up-to-date scientific instruments for testing and otherwise dealing with the operation of the plant. The calorific value of the gas is also a very important factor. I notice that the author states that for a 30 ft. × 8 ft. Lancashire boiler to evaporate 6,000 lb. of water it would require 71,000 cubic feet of gas per hour at 107 therms per cubic foot. If the gas can be supplied at 1½d. per 1,000 cubic feet this would work out to about 9s. per hour for the gas alone. I do not at the present day think, however, that gas at 107 therms can be supplied at 1½d. per 1,000 cubic feet. I shall be pleased to hear the author's views if he thinks it will pay to put down a special plant for the production of gas for gas-firing boilers, and what would be the lowest capacity of such a plant to justify the outlay. He does not seem to say much about the length of the flame and also the best position of the burners. The gas-firing boilers which I have seen have usually been fitted with the burners in front of the boiler, and the flame, about 10 to 12 ft. long, directed to the back of the boiler. After more scientific research has been achieved it may in time be possible to gas-fire boilers from a special gas-producing plant, but at the present time I do not think it is a paying proposition unless perhaps in the case of blast furnaces.

Mr. W. N. Y. King: The present paper is a fitting sequel to the Chairman's address three weeks ago * when the importance to our industries of a cheap electric supply was urged, as the use of waste gases for firing boilers contributes to this end. To anyone interested in steam-raising with coal as fuel, the use of other substances as fuel naturally appeals, and for some time past I have made inquiries and notes on this subject, so I find many points to be remarked in this paper. I do not agree with the author that lack of books on the subject is the cause of the slow progress in gas-firing, but rather the fact that gases so used were regarded as waste and owners and engineers were well satisfied if any gain was made by their use. However, as the author points out, the maximum efficiency must now be aimed at. An important factor in this connection is the question of dust in the flues. In a paper on "Waste-heat Boilers in Steam Plants" read by Mr. C. J. Bacon before the American Iron and Steel Institute † open-hearth practice is referred to and it is stated that dust is blown off the tubes every six hours. This is a serious item, as in the case of coal-fired boilers two or three times a week is considered quite frequent for this operation. The result of leaving the dust on the tubes would be a great loss of efficiency on account of reduction of heat transmission; the amount of this is shown in some figures recently published in the *Electrical Review and Western Electrician* (September 1917) as follows:

Thickness of soot on tube	0	$\frac{1}{32}$	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$ in.
Loss of conductivity ..	0	9·5	26·2	45·3	69·0 %

The use of waste products as mentioned has been tried at various times and the main difficulties to successful working have been reduction of output from the plant due to the large amount of refuse, and the increase in labour costs and difficulty of disposing of the refuse. Even with coal of the quality obtainable at the present day the handling and disposal of ash and clinker is a serious item of expenditure. The infiltration of air has an appreciable effect on the efficiency; boilers should be fitted with tight casings and these maintained in good order to reduce losses to a minimum. No reference is made to explosions, which occur at times owing to unburned gas accumulating in the flues. These are not often so violent as to distuib the stability of the boiler, but affect the walls, loosening the joints, which must be made good again if heavy losses due to air infiltration are to be avoided. It would be interesting to have some information from experience with regard to this.

Mr. W. Wilson (*communicated*): The major part of the paper has been devoted to the question of utilizing waste gases for the raising of steam. In this respect so complete and methodical a statement of the present position must be of great value to those who are studying the problem of designing to suit the new conditions. With regard to producer gas as a boiler fuel, there seems little doubt that, as the author has said in his introduction, its use is bound to develop —if only to remove the reproach so frequently levelled against electrical engineers, of wasting many of the most valuable constituents of the coal. Producers are not used to any extent in this country for electricity-supply purposes, and the few in existence use only the most favourable coal; but in other parts of the world they are much more common. In New Zealand, for example, quite a considerable proportion of the total number of power-houses are gas-driven, employing of course explosion engines, which in several cases are of the four-cylinder type. None of these stations use anthracite, and only about one-half depend upon coke, the rest consuming to a large extent a good lignite which is abundant in parts of the North island. With gas engines the complete extraction of the tar before admission to the cylinder is of great importance, and has proved a difficult matter. It has nevertheless been successfully accomplished either by the careful use of the centrifugal extractor combined with other cleaning processes such as the sawdust scrubber, by working at a temperature sufficiently high to "crack" these refractory hydrocarbons, or by the admission of air at intermediate stages in a down-draught type of producer. Still, capable management has been necessary, and where this has not been forthcoming, shut-downs have not been unknown. By utilizing the gas as a boiler fuel the traces of impurity left after the extraction of the by-products would be of no importance, and there would seem to be a special opportunity for gas-firing when such a grade of coal occurs. The use of wood (the local "tea-tree sticks"), and even sawdust, for feeding gas engines has been resorted to, although not regularly employed when coal is available. The author has mentioned the possibility of turning waste materials, such as belt-pickings, to account, and the great accumulations of sawdust and fragments in timber-working regions should present even better opportunities. A further advantage of the use of producer gas for the generation of steam, as against its use in explosion engines, is that in the former case the presence of the sensible heat is a decided benefit, while in the latter it not only actually lowers the efficiency, but is detrimental as well and must be removed. It may be of interest to note that with one of the types of down-draught producer for lignite no steam is used, the natural moisture in the coal supplying all the water required for the reactions. This circumstance should also favour its use for boiler-firing.

Mr. T. M. Hunter (*in reply*): With reference to Mr. Engholm's remarks: in the example given in the paper 71,000 cubic feet of gas of 107 therms per cubic foot were required to evaporate 6,000 lb. per hour in a Lancashire boiler. This gas is blast-furnace gas. I know of no case in this country in which blast-furnace gas is sold; but if it came to be sold, the price would more probably be ½d. per 1,000 cubic feet than 1½d.

Mr. King has asked for information as to explosions in connection with gas-fired boilers. While there is always the possibility of having an explosion, so long as we are dealing with a highly explosive fuel like gas, explosions should be as rare and as easily avoided as in the ordinary use of gas in dwelling houses. My experi-

* *Journal I.E.E.*, 1918, vol. 56, p. 48.
† Abstracted in the *Mechanical Engineer*, 16 July 1915.

ence is that explosions are due to carelessness, or to faulty plant. I once saw an example of the former when lighting up a Lancashire boiler with Mond gas. The boiler man brought his torch and opened the gas valve a little. Just at that moment his torch went out, and he proceeded to relight it without closing the gas valve. In a few moments he came back and stuck the torch into the flue. The flue was filled with an explosive mixture, and naturally it exploded. Fortunately a large manhole cover at the back blew off and relieved the pressure, and no harm was done. The boiler man told me that this often happened, and that sometimes they had blown the covers off the whole range of nine boilers at once. Of course, such carelessness was most dangerous, and if knowledge of such a practice had come to the manager no doubt he would have been able to put a stop to it finally. Minor explosions occur inside certain types of badly designed burners when the gas pressure is lowered and the burners light back. This has happened at several works I have visited, and in many cases the boiler men have been badly burned. I have only been able to advise that, so long as that special form of gas burner was used, the greatest care must be taken when near it if the primary air inlets are open and if gas pressure for any reason is lowered, or if the burner is being shut off. A well-designed Bunsen type of burner lights back when the gas pressure is lowered, but there is no explosion to harm the attendant. One other explosion may be described, which was also due to faulty plant. Coke-oven gas was being burned in one Lancashire boiler, and the other three boilers of the range were fired with coal. The gas-fired boiler was fitted with burners to take the gas at the usual 2 in. to 3 in. pressure, and all the surplus gas from 50 ovens went to this boiler. An explosion occurred which blew out some of the brickwork at the ends of the flues; and a similar explosion happened a day or two later before the cause had been discovered. Then it was noticed that the gas pressure at times rose to 10 in. or 12 in. as this boiler was the only outlet for all the surplus gas from so many ovens. When this happened, the volume of gas, pouring into the boiler flue, extinguished the flame, as there was not enough air to support combustion, and the gas-air mixture, pouring through the flues, was ignited at a neighbouring coal-fired boiler and blew out some brickwork. When this was discovered it was easily remedied by arranging a relief valve, consisting of a water-sealed downcomer pipe which blew off at 4 in. pressure.

Scottish Local Section, 11 December, 1917.

Mr. F. Anslow: I wish to speak upon one or two points in connection with the utilization of blast-furnace gases. Up to recent times all the steam required for use at blast furnaces could be produced by the waste gases, even if these were inefficiently used. Developments have taken place, however; the introduction of ammonia recovery first increased the demand for steam, and emphasized the necessity for economy in the use of the gases. Then the development of electric power generation and transmission pointed the way for wide and valuable means of using all the power derivable. In the future the need will be even greater, as with the growing tendency to erect steelworks as close as possible to the blast furnaces, such works will form an outlet for all the surplus power which can be produced. The valuable data which the author has placed before us to-night should be of assistance to all those interested in improving the efficiency of boilers fired by waste gases. Up to the present, the gas engine (notwithstanding its drawbacks) has held its own, primarily on the score of efficiency. It is generally concluded that about double the power can be obtained from the waste gases if used direct in gas engines instead of being used for steam-raising with turbo-electric generation. If the boiler efficiency (which the author estimates to be on an average 50 per cent) can be improved to the higher figure he mentions, it will considerably enhance the claims of the turbo-electric proposition. It would be interesting to know, therefore, if the 85 per cent efficiency he refers to represents an actual case under ordinary working conditions. With gas-cleaning and other apparatus available, such an efficiency should be quite possible, notwithstanding the conflicting features of the process of cleaning and burning gases. With improved boiler efficiency an additional advantage arises in connection with coke-oven gases, which are not suitable, or at least not desirable, for use in gas engines, but are very suitable for steam-raising. Upon this point it would be interesting to know whether the author has any experience of a burner suitable for burning any mixture of both blast-furnace and coke-oven gases. I believe it has been done on the Continent, but not with very satisfactory results, and it appears to me that they would be better dealt with in separate batteries of boilers with burners specially designed for the gas to be burned. With regard to producer-gas plants laid down for steam-raising purposes, I do not think much can be said about this under present conditions. In pre-War days this development was helped by the introduction of comparatively small plants suitable for ammonia recovery, and it appeared as though the system would become economically possible. There is, however, a definite relation between the cost of coal and the selling price of by-products, upon which under the present abnormal conditions, it is difficult to form a definite opinion.

Mr. W. M. Selvey: I have been interested in gas-firing since the early days of coke ovens. It has been, I think, a matter for great regret that the makers of water-tube boilers have not been at all able to cope with the demands for plant during the last 18 months, so that it has been necessary to put down very large numbers of Lancashire boilers. Had it been possible to obtain water-tube boilers freely, a tremendous amount of coal would have by now been saved, and a considerably higher efficiency obtained, not only in gas-fired boilers but also in coal-fired boilers. I

have elsewhere put forward the view that the early standardization of a Lancashire boiler has done more to check power developments in this country than any other one cause. I believe this is so, because a Lancashire boiler although very reliable, affords practically no opportunity for variation of design. The water-tube boiler on the other hand, with its subdivision of surface, forms an ideal arrangement for variation of design to meet almost any conceivable conditions. In the early days of the utilization of blast-furnace gas the efficiency of the boiler appeared to matter very little since there was generally surplus gas. To-day, with a tendency to combine manufacture with the production of pig iron, the gas has become inadequate and the efficiency of the boiler of first-rate importance. The water-tube boiler can be run perfectly well on uncleaned gas. The matter is becoming of increasing importance because we are beginning, and shall continue, to utilize home ores on a large scale, and these compared with hæmatite are called poor. This signifies that much more coke will be required. It is estimated by geologists that were we to become entirely dependent on our own ore in this country, we should require practically the whole of our coking coal to keep the ovens going. If this be so, there is no more question at all about by-products, as these will be provided in abundance. On the other hand, it makes the question of gas utilization of much greater importance. The tendency would be to coke, to smelt and to refine in the same works, wherever land is available. The real question to be settled for the future is the alternative schemes of large gas-engine stations feeding into an extensive transmission system, or very efficient boilers plus large turbines. I believe it to be a fact that these competing systems are very close together in their net results, provided that the author's high efficiencies are realized. I have carried out very extensive tests on boilers fired with coke-oven gas, which have given running results of over 80 per cent for long periods.

Mr. R. B. Mitchell: I should like to ask the author whether it is practicable to use gas-firing in conjunction with coal-firing in boilers. Before the War broke out I went over a small cruiser belonging to the British Navy and the boilers were fitted with furnaces to burn coal and oil at the same time—the oil being used when a spurt was wanted. It occurred to me that in an electrical station these same conditions often apply. We want to put on a considerable spurt over the peak and also in cases of sudden fog.

Mr. H. A. McGuffie: There are one or two points upon which I should like to have the author's views. With regard to the dust collecting upon flues on the tubes, especially of the water-tube boiler, has the author had experience of washed gas causing this trouble, traceable to tar even with wet washing plant? Another point is the minimum figure for the value per ton of steam at collieries. That may apply in England, but I do not think it applies in Scotland. The figure given by the author is 1s. 3d. per ton. I notice lately one of our largest colliery proprietors gives the figure at 10d. per 1,000 lb., which I think is fair for Scottish collieries. The author's figure of 10 per cent loss in lowering the bell seems too high; I have not been able to get a higher value than 5 or 7 per cent. I agree that there is nothing to beat water-tube boilers for gas-firing if suitable water can be got. The question of air leakage in boilers becomes a somewhat difficult problem, especially if we are dealing with coke-oven plant with two batteries of ovens and boilers in the centre. It seems easy to stop air leakages; there are, however, other leakages such as those in the underground flues and the passages at the back of the boilers, especially if the chimney is close to the back of the boilers. In these cases the method suggested of tarring could not be applied. Of course it is not possible to investigate the leakage internally while the boiler and flues are hot. Has the author had any experience of air leakage on boilers, brickwork, etc., laid down between coke ovens?

Mr. J. H. R. Kemnal: The conditions that apply to gas-firing vary very much, according to the kind of gas used, and the theory that may apply in the case of producer gas, or coke-oven gas, or waste gas from open-hearth furnaces (waste heat), is not one which may be applied to the utilization of blast-furnace gas. Taking producer gas first, it is generally conceded that there is very little advantage to be found in merely producing gas for the sake of firing it under boilers. It can only be made to pay if by-products are recovered, and the value of the by-products reaches a certain figure. Dealing with waste heat or waste gas from open-hearth furnaces, there are many installations now, both in America and in this country, and it is well known that in this case artificial draught is required, so that the recovery of the lost heat in the waste gases shall not interfere with the proper working of the furnaces. So far as the burning of coke-oven gas is concerned, this is an extremely simple matter, and generally nothing more is required than to lead the gas under the boilers. There is generally no question as to the water-tube boiler being the best type for firing under the conditions mentioned, but, reverting to the subject of firing with blast-furnace gas, which is probably the oldest form of application of gas for steam-raising, it must be borne in mind that in the blast furnace the gas is a by-product, and the most important thing is the satisfactory working of the blast furnace itself. Usually there is such a surplus of gas for all purposes in purely blast-furnace installations that the highest possible efficiency is not regarded as of the first consideration; and the introduction of refinements, requiring additional upkeep, is not always justified. The author gives a comparison between the Lancashire boiler and the water-tube boiler. There are large numbers of Lancashire boilers in use, utilizing blast-furnace gas, but a still larger number of water-tube boilers, and comparing the two, I can state, from many years' experience, that the water-tube boiler has very great advantages. The disadvantage of the ordinary two-flue Lancashire boiler was years ago sought to be remedied by the three-flue Lancashire boiler, but neither type is advocated very strongly at the present time. Dust in a water-tube boiler can readily be got rid of by frequent application of steam blowers,

either fixed or portable, and by constructing dust chambers in front of the boilers, but this cannot be done in the Lancashire boiler, and my experience is that with the Lancashire boiler the capacity falls off in one-fourth of the time that it does in the water-tube boiler. In referring to the water-tube boiler, I mean the standard industrial types. There have been cases, such as those the author refers to, of the flue dust becoming so hard that scrapers have been necessary to get it off the tubes, but these conditions generally result from initial neglect. If the soot-blowing is attended to at the start, the dust can be prevented from caking; but if this is neglected and a film is allowed to accumulate, this film more readily attracts additional dust and a cake is the result, requiring stronger means than the steam jet to remove it. There is another point mentioned by the author in regard to the application of water-tube boilers, in which my experience is absolutely at variance with his views. He thinks that good results may be obtained in a boiler of the Yarrow type with high velocity across the tubes, or rather, better results than with an ordinary water-tube boiler, with the velocity due to a good chimney draught. My firm have made experiments with restricted gas passages and found them to be detrimental. On the other hand, we have found advantages to result in some cases from increasing the spaces between the tubes in the Babcock & Wilcox boiler beyond the normal spacing. Another point with blast-furnace gas is that for every 100 cubic feet of utilizable gas a great volume of unutilizable gas has to be carried, and that is another reason why large passages between the tubes, and a large chamber to enclose them, are essential. With regard to washing blast-furnace gas, I remember a plant of boilers we put down in which this was tried, but the washing of the gas required a very elaborate installation, and the results were not so good, largely, I think, owing to the heat lost in the process of washing. Another form of utilizing gas which I have been investigating with a great deal of interest, is the arrangement in the Bonecourt boiler, and perhaps a few words on this subject may be of interest. This boiler, as is known, is a big shell with a lot of tubes going through it. The latest design is one in which 6-inch tubes are used. At one time these tubes were filled with broken brick to ensure surface combustion, but the broken brick did not answer, as it choked too readily, and there was substituted an arrangement of segmental bricks which form a coating about 1 inch thick inside the tube. A high combustion is obtained in each tube by carrying the gas and air under pressure into each tube from a separate burner, and the resultant heat of combustion is transmitted through the brick to the tube. The application of both air and gas under pressure requires a considerable amount of auxiliary apparatus, and the restriction in each tube, forming a separate combustion chamber, necessitates a very high rate of draught to get the products of combustion away. This application is certainly interesting. Whether the figures published of the total efficiency are quite sound, I do not know; but even supposing the very high efficiency referred to is obtained, the whole arrangement is, I consider, impracticable except in a very few cases. One of the drawbacks is that the size of the unit is limited to a capacity below 20,000 lb. of steam, and that, for power plant, is looked upon as a small unit nowadays. The application, however, certainly approaches the possible theoretical conditions of combustion more closely than it is possible to obtain with any other form of combustion chamber. Reverting again to the question of burning blast-furnace gas under boilers, it is very difficult to argue that one form of furnace is very much better than another. The best form of furnace depends upon a lot of conditions, and must be studied in each case.

Mr. T. M. Hunter (*in reply*): Mr. Anslow has mentioned the use of blast-furnace and coke-oven gas, mixed, for boiler-firing. The mixed gas would be considerably richer than blast-furnace gas alone, and so far as this is concerned would be better than the poorer gas. It is, however, a very difficult matter to mix gases intimately without using a mixing fan, and, in addition, the quantities of each gas would be sure to vary, so that the calorific value of the mixture would be expected to vary considerably. For these reasons I should not expect to get a good boiler efficiency from the mixed gas, but should much prefer to keep the gases separate and fire them at different boilers. I know of one case in Germany where mixed gas is burned in Lancashire boilers, the mixing being done simply by leading down the two pipes to a common pipe above the burner. No attempt is made to mix the gases intimately. Unless the quantities of the two gases are kept constant, the results are sure to be bad. Not only will it be impossible to supply the right amount of air for a gas varying in calorific value, but also poorer and richer gases require burners of quite different proportions, so that no burner could be made which would be suitable for all the conditions. I do not understand why the Germans ever installed such a very crude arrangement.

Mr. Selvey has spoken of the advantages of water-tube boilers compared with Lancashire boilers. I agree with him as regards the introduction of new boilers, but I am continually called upon to deal with boilers already in existence. It would not be a paying proposition to take out Lancashire boilers and to install water-tube boilers for the sake of the added efficiency. The only place where the water-tube boiler has a great advantage is in burning uncleaned blast-furnace gas. On the other hand, at many works the Lancashire boiler is preferred because of the large reserve of steam it contains to meet sudden demands.

Mr. Mitchell has asked as to the possibility of gas-firing and coal-firing boilers simultaneously. This is the usual way in which boilers are now fitted up, the gas burners being placed above the fire doors, both in water-tube and in Lancashire boilers. This can be done in most water-tube boilers, even though they are fitted with mechanical stokers. When gas is being used and fails for any cause, coal-firing can be started without a moment's delay, and the gas-firing equipment does not in any way interfere with the usual working of the boilers with coal.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 56. MARCH, 1918. No. 272.

THE NINTH KELVIN LECTURE.

KELVIN AS A TEACHER.

By Professor MAGNUS MACLEAN, D.Sc., Member.

(Lecture delivered before THE INSTITUTION, *7 February*, 1918.)

During the 15 years I acted as Lord Kelvin's chief official assistant, I attended every lecture he delivered, both to the Ordinary and to the Higher class, and I always took notes. One reason why I took a few notes in the case of the Ordinary class was because the lecturer had a habit of devoting some minutes at the beginning of each lecture to oral examination, and got into the way of throwing the first question at me. "Maclean," he would ejaculate, "oh, what did I lecture on last day?" To the student the oral test was a dreaded ordeal. In front of Lord Kelvin lay the class record-book open, with the names of the students arranged numerically in their benches. Glancing down the list, he quickly selected a name, and its hapless owner was called up. A question was immediately put to him, the examiner looking straight up tor a reply, with monocle usually on his right eye, his left forefinger on the name, and pencil in his right hand, ready to record. In most cases the student stood speechless, as if affected with aphasia. The question was put in other forms, and no answer forthcoming, the student was peremptorily asked to say "Yes" or "No." Finally, when the puzzled youth would not venture to commit himself, there came the sarcastic, "Please say Yes," and without further waiting, the pencil descended and a mark was put in the record book. I suppose students thought that this mark would be taken into account in deciding the final reckoning for class tickets. As a matter of fact it was simply the letter e to indicate that he was orally examined, the length of the tail of the e depending on the degree of exasperation which Kelvin had reached when he asked the student to "Please say Yes."

My reasons for taking full notes of the lectures to the Higher class were; (1) for my own instruction, (2) for Kelvin's help and guidance in his next lecture, as he very often wanted the last equation of the previous lecture reproduced exactly as he left it. The subjects were varied from session to session: Elasticity, Hydrodynamics, Theory of Heat, Theory of Light, Electromagnetic Induction, respectively occurring 6, 4, 3, 2, 1 times in the 16 sessions during which I was first student and then assistant. Electromagnetic Induction happened to be taken in the session 1890–91, and I give a few quotations as "illustrations.": –

November 12, 1890, Lecture I. "In alternating currents, the distance of penetration is proportional to the square root of the period. By distance of penetration is meant the place where the maximum current is equal to half the maximum current at surface. It follows the same law as underground temperature—earth under the heat of summer and the cold of winter."

December 3, 1890, Lecture IV. "Four reasons for a hot armature: (1) magnetic friction (inevitable), (2) electromagnetic induction in iron (practically annulled by proper distribution of iron—flat rings of thin iron separated by non-conductive material), (3) vicious electromagnetic induction in the conductor of the armature—cross currents circulating in the conductors, (4) true induced current, the generation of which is the object of the machine."

December 10, 1890, Lecture V. "To show that conductance in Electrostatics is a velocity. Take an insulated metal sphere in the centre of a room, and suppose it to be losing electricity slowly by the insulating support or otherwise by a moist thread. Suppose the sphere to be uniformly contracting so that its potential (Q/r) is keeping constant, then the velocity of approach of the surface to the centre is the conductance of the thread."

February 25, 1891, Lecture XIV. "The discussion was on 2 circuits α β currents, R S resistances, I J P inductances, and $\sin \omega t$ the unit E M F in one circuit

$$\left.\begin{aligned} P\dot{\beta} + (I\dot{\alpha} + R)\alpha &= \sin \omega t \\ (J\dot{\alpha} + S)\beta + P\dot{\alpha} &= 0 \end{aligned}\right\} \dot{x} = \frac{dx}{dt}$$

If $\beta = 0$, $\alpha = \frac{\sin \omega t}{I\delta + R}$

$$= \frac{(I\delta - R)\sin \omega t}{I^2\delta^2 - R^2}$$

$$= \frac{\omega I \cos \omega t - R \sin \omega t}{-I^2\omega^2 - R^2}$$

$$= \frac{R \sin \omega t - I\omega \cos \omega t}{R^2 + I^2\omega^2}$$

generally $\alpha = u + $ " "

where u is any solution of $I\frac{du}{dt} + Ru = 0$.

. . . . . .

. . . . . .

$$[(J\delta + S)(I\delta + R) - I^2\delta^2]\alpha = (J\delta + S)\sin \omega t$$

$$[(J\delta + S)(I\delta + R) - I^2\delta^2]\beta = -I\delta \sin \omega t$$

$$\alpha = \frac{(I\delta + S)\sin \omega t}{(I J - I^2)\delta^2 + (I S + R J)\delta + S R}$$

$$= \frac{(I\delta + S)\sin \omega t \left\{[(I J - I^2)\delta^2 + S R] - (I S + R J)\delta\right\}}{[(I J - I^2)\delta^2 + S R]^2 - (S I + R J)^2\delta^2}$$

$$= \frac{\{-(I I^2 - I I^2\delta^2 - I S^2 R\} - \{(S I^2 + R I^2)\delta^2 + S^2 R\}}{\omega^4 (I J - I^2)^2 + \omega^2 (S^2 I^2 + R^2 J^2 + 2 S R I^2) + S^2 R^2} \sin \omega t$$

$$\beta = \frac{(I J - I^2)\delta^2 + (I S + J R)\delta + S R}{\text{same denominator}} I \sin \omega t$$

Write for δ, $\omega \cos \omega t$.

" δ^2, $-\omega^2 \sin \omega t$, etc.

Then particular cases are given, R = 0; P as large as possible, and I and J not larger than may be; $P^2 = I J$; find rate of doing work, etc."

There was no systematic course of instruction in the Laboratory. A number of Thomson scholars were always engaged in experimental research, and new students were attached singly or in pairs to each scholar, and had to help in making observations and devising new apparatus. In this way students got practice in wood-work, sawing, planing, and fitting. Nothing was done for them. If a student had to solder, he was required to do it himself, and with resin, no chloride of zinc being allowed. True, he had an opportunity of seeing how it was done by a senior student or scholar while he was at the stage of looking on and helping. But Kelvin's attitude to beginners is quite explicitly enunciated in letter 30, April 23, 1895, where at the end he says, "Let any students, if there be any, stand by and learn, and help when they can." Since then I have had 18 years' experience in the Royal Technical College, Glasgow, where students are put through regular courses of laboratory practice. Sheets of instructions are given them beforehand, apparatus laid out to be connected up by the students themselves, rules given for entering results and drawing graphs, all of which must be entered into special laboratory books, which are examined and criticized by the teaching staff at frequent intervals during the session. Kelvin's method, or, shall I say, want of method, had many disadvantages, but the more modern methods prevalent in every British laboratory are by no means free from defects also

He was impatient about investigations set to the Laboratory staff. Before the experimenter had time to arrange the apparatus he would suddenly get up from his table and green book to ask for results. He was quick in temper, as in mind. Little mishaps, or an apparent want of economy on the part of a student, often sent the great scientist into a paroxysm of passion. For example, if a student were found twisting two bare copper wires together to form a metallic junction instead of using a binding screw, he would inevitably be subjected to a severe lecture on the waste of what Lord Kelvin called "good and dear material."

Incidents of this kind stand out prominently in my own experience while assistant. It had been one of my duties, in conjunction with the mechanic, to prepare the previous afternoon all the experiments he deemed necessary for the lecture next morning. This frequently involved hours of work. But, alas! to our chagrin, next morning an unanswered question by a student in the oral examination set the lecturer off at a tangent to discuss subjects quite different from those that were to be illustrated by the experiments prepared. This was no uncommon occurrence, and, of course, very irritating to the one whose labour was wasted. I think it was towards the end of my first session that the subject of polarization of light came up for discussion. On a table in a bay window at the south side of the class-room lay apparatus to show polarization by reflection, including the effects seen on compressed glass as viewed by polarized light. There we had laid out strips of glass six inches long and half-an-inch broad, which were to be bent in their own plane while being viewed through a Nicol's prism. Some students accidentally, or through ignorance, bent them in the wrong plane and broke the strips to pieces. I suppose the shattered apparatus had been in the window for several days, when immediately after one of his lectures, Lord Kelvin came into the apparatus room with one of the short, broken pieces of glass in his hand and asked me in an angry tone what I meant by putting on the table such a specimen. In reply I inquired in an equally angry tone what he meant by bothering me about a broken bit of glass when I was busy with other official duties. In a few seconds, or it might be a few minutes, it would be hard to say which of us was the more speechless. It was my first and last temper tussle with him. From that time he understood that I was not to be lightly roused, and I, on my part, respected his impulsive disposition. Our relations became more cordial, and instead of asking for dozens of experiments to be got ready for him, he would look in during the afternoon and ask what I had ready; or if I did not see him the previous afternoon I would hand him a slip of paper in the morning with a list of the experiments which were ready on the table, and a heading or two announcing the subjects on which he was to examine the students orally. And so on January 31, 1898, letter 58, it will be observed that he wrote: "I shall be glad if you will arrange to let me meet the Ordinary class on Wednesday, and the advanced at

noon the same day. I hope you can do this without inconvenience."

Another very good illustration of a sudden demeanour occurs in a postscript to one of his letters from London, added by his secretary at that time :—

"I had a terrific piece of fun yesterday; in the calculations there was the occurrence of $\gamma = 3{\cdot}3$, and Lord Kelvin got completely, confusedly mixed up altogether between the 3·3 and 3·3333 and the $3\frac{1}{3}$ and 10·3, and he treated me to an ecstatic performance with his two hands, his face, and his shorter leg in a sitting posture. I persisted in doing what he thought was wrong but what was really right; the idea that my way was after all right struck him when he was in the height of one of his writhings, with his hands all spread out, and the sudden transition to tranquillity was indescribable."

A curious sidelight on his many activities occurs at a later date, when another secretary wrote as follows from London :—

"This has been a busy day for him. He only arrived here about 12 this morning, having been out of town over the week-end. Then at 1 p.m. he had to go to a levee at St. James's Palace, so sallied forth in the full glory of a 'cocked hat,' court dress, knee-breeches, and a sword! and, of course, giving me instructions all the way down the stairs. Then he was no sooner home than he had to get ready to go to the House of Lords, where he is now."

My impressions as a student in his class may be given in a quotation from an obituary notice I wrote for the *Scotsman*, and which appeared in that paper on the 18th December, 1907 :—

"I well remember the first day I attended his class in Glasgow University. The devout attitude in which the Professor offered up his morning prayer struck me forcibly. An ancient-looking manuscript of 1846, yellow with age, was produced, and portions of it read, in which he tried to differentiate between the two great provinces, mind and matter. Then followed a laboured disquisition on the common restriction of natural philosophy to the treatment of inert matter, though he held that it was quite as natural to include mind and its philosophy. Having disposed of this point, the lecturer went on to distinguish between natural history and natural philosophy, and to define exactly mechanics and dynamics. At this stage the manuscript was thrown aside, and the rest of the hour devoted to a general exposition of dynamics.

"A few indelible impressions have been left on my mind regarding the work of the class. Most memorable for various reasons was the ballistic pendulum day. A long array of symbols and formulas confronted us on the blackboard when we got into the class-room, and these we were informed had been worked out by his assistant, the late Mr. Macfarlane. On that particular day we had a learned, and, to some of us, mystifying, discourse on impulse, momentum, and moment of momentum. Then towards the end of the hour the assistant handed him an old Jacob's rifle. Seizing hold of this, Kelvin spent some time in getting down on one knee in front of the class, laying the rifle in wooden V grooves which had been accurately placed beforehand by the assistant, so that a bull's eye could not be missed at three yards' distance, and finally adjusting his eye-glass on his right eye. After considerable movements of this kind the gun was at last fired, accompanied by the cheering of the class of about 200 students. The assistant read eleven as being the number of centimetres the tape was drawn out by the bob of the pendulum. Substituting this number in the formula on the board we read (we could not hear) that the velocity of the bullet was 880 feet per second. We had other very exciting incidents that session, such as the spinning of boiled and unboiled eggs, and of all sorts of gyrostats, the bursting of a big indiarubber bag containing many gallons of water, designed to illustrate the formation of a dew drop, the turning of the big wheel in the window to find the horse-power of two students. But the last day of my course is the most vivid of all. We had had no lectures on sound during the previous part of the session. But this day, strange to behold, the lecture table was crowded with all sorts of apparatus on the subject—monochord, siren, sand plates, tuning forks, organ pipes, French horns, etc. The lecture began at 9 a.m., at 10 o'clock he announced that any one who specially wanted to leave for another class could do so, but that he wished to show one or two other experiments in sound. A similar announcement was made at 11, and again at 12. The last experiment was shown at 12.30 and the dozen of us who were left vigorously sang 'Auld Lang Syne' at the close."

In 1901 I read a paper on "Kelvin's Electric Measuring Instruments." * At the beginning of the paper I classified them as follows :—

(1) Electrometers.

(2) Electromagnetic Instruments for measuring currents and differences of potential.

(3) Electro-dynamic Instruments for measuring currents and differences of potential, and electric activity.

(4) Instruments arranged for recording and integrating electric currents.

The instruments were also classified as :—

(1) Standard Instruments (6 sub-headings).
(2) Portable ,, (8 ,, ,,)
(3) Central Station ,, (10 ,, ,,)

It is noteworthy that a considerable number of the instruments described and illustrated in the 1901 Paper are not now being manufactured. Those which are still manufactured have been subject to continual improvement of detail and arrangement to meet the varying conditions of practical use and manufacture, but the basic principles as laid down by Lord Kelvin are maintained in their design.

The *ampere balances* have been modified in detail, in view of their extended use on alternating-current circuits.

The *watt balances* have been for some time in process of complete re-design, so as to reduce the possibility of error due to eddy currents in the main conductors and metal parts of the instruments in the neighbourhood of the coils. Those dealing with large currents

* *Journal I.E.E.*, vol. 31 p. 177.

employ concentric main conductors, by which errors due to eddy currents and skin effects are eliminated and a robust construction retained. These are being manufactured in collaboration with Mr. A. E. Moore.*

In the Multicellular Voltmeters the casings are insulated on the outside surface, thus providing safety while maintaining efficient screening. By the use of non-inductive resistances with suitable tappings for multipliers, multirange instruments of various kinds are available. The general arrangement of one form of the instrument is shown in Fig. 1, which illustrates the portable pattern, in an outer wood case.

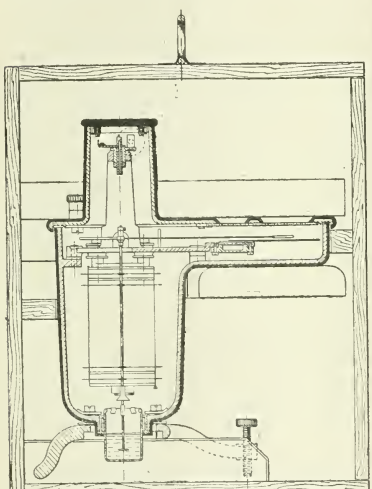


FIG. 1.—Portable pattern multicellular voltmeter.

The rail-bond testing instruments now make use of the bridge method, and the indicating instrument is a moving coil galvanometer. The contacts applied to the rails are similar to those in the older instrument, but are at a fixed distance apart and are constructed in hardened steel with cutting edges to effect efficient contact on the rail surface. The present instrument is much lighter than the earlier pattern described in my 1901 paper. The general arrangement is shown in Fig. 2. The centre knob is turned till the galvanometer pointer seen through the little window shows zero, when the relative resistance of bond and solid rail is shown by the position of the pointer attached to the knob. The connections are indicated in Fig. 3.

Recording Ammeters and Voltmeters and Feeder Logs. For direct-current work the moving coil type of instrument is now invariably used instead of the older coil-and-plunger pattern. The use of the moving-

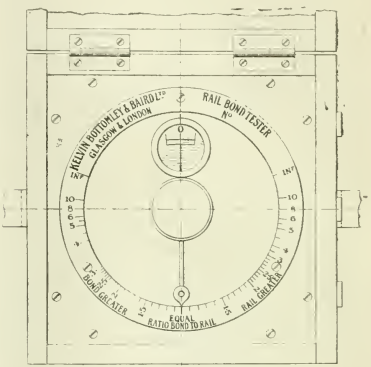


FIG. 2.—Rail-bond testing instrument.

coil instrument enables large currents to be dealt with by means of shunts, and also admits of the instruments being standardized as to sensibility.

The coil-and-plunger pattern ampere gauge has also been replaced by the moving-coil type of instrument

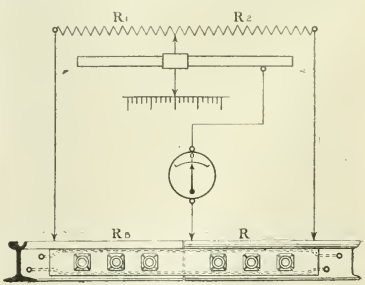


FIG. 3.—Rail-bond instrument connections.

for direct-current work. A new pattern "moving iron" instrument is manufactured for alternating-current work, in which the form of, and the flux density in, the moving iron is so arranged that large changes of frequency or of wave-form are practically without effect

* See paper by A. E. Moore on "New Concentric Standard Dynamometer Wattmeter for Heavy Currents: and Concentric Non-Inductive Standards of Low Resistance," *Journal I.E.E.*, 1917, vol. 55, p. 380.

on the instrument. They are damped pneumatically instead of by an oil dash-pot, and are thus more portable.

The portable indicating wattmeters illustrated in Figs. 4 and 5 have a minimum of metal near the active coils, and that metal is of very high specific resistance. This eliminates eddy current errors for all practical purposes. The whole of the movement and the fixed coils are rigidly carried on a base casting which is machined out in order to form

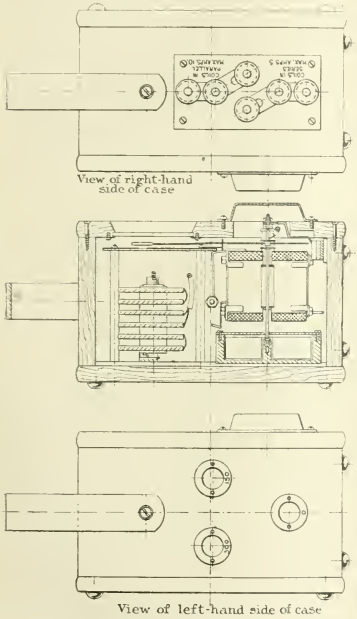


FIG. 4.—Portable wattmeter.

the damping chamber, in which chamber there move two light vanes attached to the movement spindle. The instrument, as shown, can be arranged for voltages up to about 500, and by means of the change-over links on the current terminals two ranges can be obtained by putting the main coils in series or in parallel. The main coils for large currents are wound with stranded conductor, each strand of which is insulated from its neighbours.

During the session 1897–98, Mr. V. J. Blyth and I conducted experiments on coherers and spark discharges. The main object of the experiments was to determine whether the transmission was more effective in the direction of the spark or at right angles to the direction.

On the 3rd June, 1898, Lord Kelvin visited the Needles Station and sent from there to me the first paid marconigram, as follows: "Maclean, Physical Laboratory, University, Glasgow. Tell Blyth this is transmitted commercially through ether from Alum Bay to Bournemouth and by postal telegraph thence to Glasgow. Kelvin."

I give in an appendix a selection from a great number of letters I received from 1886 onwards. They refer to the experiments that were going on in the Laboratory

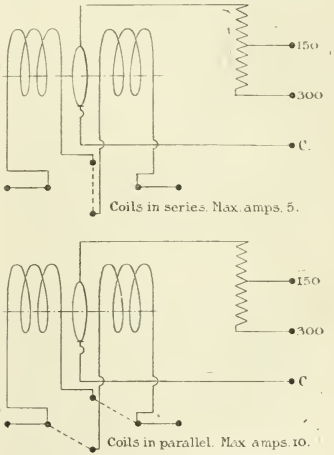


FIG. 5.—Portable wattmeter connections.

at the time, or to the calculations that were being made for one or other of his papers now published in volumes 3, 4, 5 and 6 of his "Mathematical and Physical Papers," and in his Popular Lectures and Addresses. I need not refer to them in detail; the *ber* and the *bei* are in volume 3; ship waves, and graphic solutions of graphical problems in volume 4; Piezo electricity in volume 5; electrification and diselectrification of air and other gases, and kindred subjects form nearly the whole of volume 6.

Letters (1), 7th August, 1886, and (66), 23rd July, 1899, are given in facsimile.

Some of the important results fully proved by the experiments on Electrification of Air may be stated:—

(*a*) Every drop of rain falling on the ground, and every drop of fresh water spray of a breaking wave

1

Address Portsmouth till further instructions

Yacht "LALLA ROOKH"
R.Y.S.

Aug 7/86

Dear Mr Maclean

Thanks for your letter and calculations which I return, as the shortest & easiest way of saying what is wanted.

The choice of value for a is merely a matter of convenience for drawing. You may

3

a = 1, then for small values of x, take decimals, as 1, ·2, ·4. Or omit in the calculation, and for any particular value of a & x make x = 1×a &c. All this makes absolutely no difference in the work.

Take only enough values of x to give the general form of the curve

2

make it 100, tenths for rich in millimetres or anything for fundamental.

For the calculation I dare say the most convenient way may be take a = 10, ½gt² = 10, and to take for x, 1, 2, ... 9, 10, 15, 20, ... Or if you like to take

4

You must begin with x = 0, x = 2a, x = 4a and so on for four or five values. Then take one or two intermediate values, helping yourself by the curve. For instance try next x = ·5×a, x = 1·5×a. You will soon see that you have enough to get all the main features of the curve. Beyond that I want nothing in the way of minute

5

accuracy of the present Ms
soon as you know
put the main features, and a rough
curve for comparison,
I would like to see it
I am glad to hear

6

all is going on well
in the Lecture room
and trust you enjoy
your holidays. I hope
Mrs. Maclean and
the little girl
Yours truly
William Thomson

July 23/99

28, CHESTER SQUARE,
S.W.

Dear Maclean

I thank you warmly
for your kind letter,
and for all the care
and devotion with
which you have
worked with me
and for me during
these sixteen years.

I hope you are
enjoying thoroughly
your holiday in
Skye and will return
well and refreshed
for your new
work.

Believe me
Yours always truly
Kelvin

falling on a fresh-water lake, send negative electricity from the water surface to the air.

(*b*) Every drop of salt water, falling on the sea from breaking waves, sends positive electricity into the air from the water surface.

(*c*) As more than two-thirds of the earth's surface is sea, the breaking of sea waves may be the determining cause of the normal fair weather positive of natural atmospheric electricity.

(*d*) The greatest quantity of electricity that could be given to air by needle-points at a potential of 10,000 volts was $3{\cdot}7 \times 10^{-4}$ e.u. per c.c.

(*e*) With an electrified coal-gas flame the quantity was 11×10^{-4} e.u. per c.c.

(*f*) By an electrified hydrogen flame the quantity was 22×10^{-4} e.u. per c.c.

1 electromagnetic unit quantity $3 \cdot 10^{9}$ electrostatic unit quantity.

Thus 22×10^{-4} electrostatic unit quantity $= \frac{22}{3} \times 10^{-13}$ coulomb, or less than a millionth millionth of a coulomb.

I may be excused for referring specially to the last letter, 21st December, 1905, which I quote, where the gratifying statement is made that calculations done that year corroborated mine undertaken in 1887 from a less simple and less convergent set of equations.

I have always thought of Kelvin as one of the most gifted and successful of mankind alike in his early distinction, the length and brilliance of his career, his wonderful genius, and the uniform physical health, which enabled him to carry on his work, so that almost to the end it might be said that his eye was not dimmed nor his natural strength abated. What is even more astonishing, his zest for research and his interest in all the complicated problems of the material universe never waned. He seemed to live to wrest from Nature her secrets, and it gives one pleasure to consider how much richer the world is to-day through the efforts of his giant intellect. Unlike the work of many another brilliant man, his success cannot in any sense be regarded as ephemeral, for his achievements are interwoven into the fabric of scientific progress which shall continue to help and push forward mankind.

APPENDIX.

(1) YACHT "LALLA ROOKH,"
August 7, 1886.

DEAR MR. MACLEAN,

Thanks for your letter and calculations which I return with pencillings, as shortest and easiest way of saying what is wanted.

The choice of value for a is merely a matter of convenience. You may make it 100, tenths of an inch or millimetres or anything you find convenient. For the calculation I dare say the most convenient way may be take $a = 10$, and $g t^2 = 10$, and to take for x, 1, 2, . . . 9, 10, 15, 20, . . . Or if you like to take a 1, then for smaller values of x, take decimals, say 0·1, 0·2, etc., or don't, in the calculation, assign any particular value to a, and make $x = 0{\cdot}1 \times a$, etc. All this makes absolutely no difference in the work. Take only enough of values of x to give the general form of the curve. You might begin with $x = a$, $x = 2\,a$, $x = 3\,a$, and so on for four or five values. Then take one or two intermediate values, helping yourself by the curve.

For instance, try next $x = 0{\cdot}5 \times a$, $x = 1{\cdot}5 \times a$. You will soon see that you have brought out all the main features of the curve. Beyond that I want nothing in the way of minute accuracy for the present. As soon as you have got the main features, and a rough curve, for case $g t^2 = a$, I would like to see it.

I am glad to hear all is going on well in the Laboratory, and that you enjoyed your holiday. I hope you and Mrs. Maclean are the better for it. Address Portsmouth till further instructions.

Yours truly,
WILLIAM THOMSON.

(2) NETHERHALL,
September 9, 1886.

DEAR MR. MACLEAN,

I directed Mr. Reid yesterday evening to send up some fuses to be tested for 15 amperes. If any other strength is wanted make trials accordingly. Besides trying the fusing current I want observation of the effect of the fuse going, when there is our full potential of secondary battery, 84 to 90 or 100 volts in the circuit. Arrange, therefore, by the iron wire resistance on the wall and a graded galvanometer (or the horizontal balance deca-amperemeter) to get and measure the requisite current from our electric mains. I shall see the experiments on Tuesday. I want to see if the melting of the fuse damages the mica or the glass of the fuse case. The fuses had better not be despatched till after Tuesday, unless you are quite satisfied of two things: (*1*) a five p.c. accuracy of the melting current; (*2*) that neither the mica nor glass is injured.

Wave group curves.—Did I give you $1/(a^2 + x^2)^{\frac{1}{2}}$ as the algebraic factor? I have it correctly in my green book from which I copied it for you: but I am not quite sure if I did not give it you $1/(a^2 + x^2)^{\frac{3}{2}}$. I shall be very sorry if I did, as it would entail, I am afraid, a good deal of work correcting numbers. In what you are doing or going to do now make sure you take it $1/(a^2 + x^2)^{\frac{1}{2}}$.

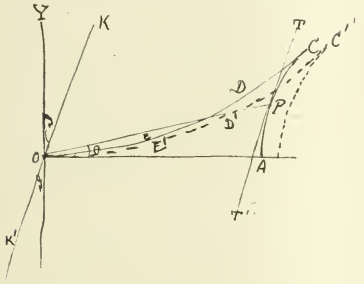
Let me have letter or p.c. to-morrow answering this and reporting fuse results and other progress in laboratory: also a short (very short) report on Monday which I may receive on Tuesday morning before I leave, or on Monday evening if it is posted before 2 p.m. I shall be at White's about 11.40 on Tuesday and hope to be in the laboratory before 1, but don't let anybody wait for me as I shall see you all after if not before lunch.

Yours truly,
WILLIAM THOMSON.

(3) LONDON,
May 25, 1887.

DEAR MR. MACLEAN,

On other side you have formula, etc., for wave model. Make the height of the ridge anything convenient. Build it up out of stuff taken from adjacent hollow. Tell me if you understand



$OA = a$, $OP = r$, $POA = \theta$, $YOK = \xi$.

Choose values of ξ from 0 to 90° enough to give good curve. Calculate θ and r as follows:—

$$\tan(\xi + \theta) = 2\tan\xi,$$

whence

$$\theta = \tan^{-1}(2\tan\xi) - \xi,$$

$$r = a\frac{(1 + 4\tan^2\xi)^{\frac{1}{2}}}{1 + \tan^2\xi}.$$

This will give you the same curve as we had before. Then calculate values of h (height of ridge) for every calculated point of A P C by the following

$$h = \frac{1 + \tan^2\xi}{(1 - 2\tan^2\xi)^{\frac{1}{2}}}$$

At C, the cusp you have $\tan^2\xi = \frac{1}{2}$, and therefore $h = \infty$.

For the branch C D B O calculate by

$$h = \frac{1 + \tan^2\xi}{(2\tan^2\xi - 1)^{\frac{1}{2}}}$$

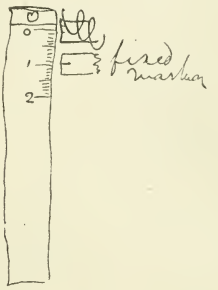
But (because h is imaginary in this branch) there is a break of phase at the cusp, and in the clay you must leave mean level all along C D B O, and make the h ridge along the dotted arc C′ D′ B′ O corresponding to the next half wave-length cusp C′. . . .

W. THOMSON.

(4) LONDON,
June 23, 1888.

DEAR MR. MACLEAN,

I have written Mr. Reid to send you on Monday a scale weight to be tried on the ampere gauge, just to see how it works. The scale is on paper, pressed between a glass front and aluminium back. I don't know what the weight will turn out to be; but take it as it is and I think you will find it within range for moderate currents. I suspect, indeed, it may be too light, and you may have to hang on a weight below to get the best range for it: which I think will be from the iron just entered 1 cm. below; up to the top end of the iron 1 cm. below the top of the coil. Clear away the stop



from below, and apply a fixed marker beside the graduated edge, so that you will easily read to $\frac{1}{2}$ or estimate (roughly) to 1/10 of the small divisions. In recorder make the $\frac{1}{2}$ mm. unity (not as you had it 0·1). Thus the scale reading represented in the sketch would be 0·5 and the scale will run from 0 to 140 (but marked only 14 on the paper). You might yourself without waiting to hear from me apply a checker if you find the oscillations wild, in the charging circuit of secondary battery. A little disc of tinplate 1 cm. or 2 cm. diameter soldered to the lower end of a wire 6 cm. long, and hanging down in a wide enough test tube would do very well. (One of those tubes we had made for small secondary battery would do.) You would need to raise the stand of the instrument and cut a hole in the bottom for this checker. Sugar dissolved in water would give any amount of viscosity you find desirable. You might perhaps try this before you have the engine going (unless it is going on Monday) if you think proper. You don't tell me if you have been troubled by vibrations. Does it come to rest very quickly in your ordinary experiments? I think the viscous checker may be wanted only for use on a secondary battery charging circuit (in which Ayrton and Perry's is so wild) and possibly it may not be needed even there. I am impatient to hear if it is, as my plans would depend very much on whether it is wanted or not.

Your last results I think quite prove that the instrument will succeed. Have you found any adverse signs of magnetic retentiveness? Your continuation of the work with higher currents and then lower will tell this. Also we must know effect of reversals. I wish to use as standard direction of current, that for which the vertical component of terrestrial magnetic force

helps. This will be useful for the weakest currents and will not be sensible for the stronger.

Yours truly,
W. THOMSON.

(5) LONDON,
July 2, 1888.

DEAR MR. MACLEAN,

When the volt gauge comes back to you I should like scales from 1 amp. by single amps. up to 5; then 5, 10, 15, 20; then 20, 30, 40, 50, 60; then 80 and 100. See how much it heats at 100. If it will bear 120 you might try it at that. The different scales are to be got by different heights of the top suspension. I don't know if there will be very good arrangement for this, but you might extemporize something. First top of spring so high that you get a good scale from 1 amp. up to as high as still gives you good readings. Then lower the top suspension perhaps 2 cm. or 3 cm. or what you find convenient: and take another set of readings, and so on. You will, I think, see your way better than I can direct at this distance.

I hope to-morrow morning to hear something satisfactory regarding the multicellular electrometers.

Yours truly,
WILLIAM THOMSON.

(6) LONDON,
July 7, 1888.

DEAR MR. MACLEAN,

Thanks for your letter of yesterday and table of results. As to ampere gauge I intend to have *two* scales, one with a visible zero, the other not. Try (for three scales first) accordingly as follows. Replace the first spring and put the heaviest weight on the piston that gives a free zero, when the top of the spring is at highest. There should be 2 or 3 half millimetres free. Is the lowest point fixed by the bottom of the dash-pot? How high is the top index button above the top of the coil when at the lowest?

Scale 1.—Make observations for one scale with top end of the spring at its highest position.

Scale 2.—Lower the top end of the spring *exactly* 4 centimetres below the former position.

Lastly, Scale 3.—Replace the top of the spring to first position and take off weight from the piston enough to raise the zero by 40 or 50 or 60 divisions (a round number not essential).

For scales (1) and (3) make observations (not too close in respect to differences) from 1 to 60.

For scale (2) make observations (not too close, but close enough to give a good scale) from the smallest current that lifts, up to 120 am.

You might construct, on blank paper, direct reading scales for two out of the three ranges (1) or (3) and (2) and fix one of them on the left and the other on the right of the index button.

What did you mean by "tapping"? Does the plunger stick without tapping? Have you used oil (finest clear paraffin) or water in the dash-pot? You had better, I think, keep oil habitually in the dash-pot; but don't do so if you see reason not to do so.

W. T.

(7) NETHERHALL,
July 27, 1888.

DEAR MR. MACLEAN,

Since your hand is in you might try the brass bobbin of No. 40 just as yesterday but with a hardened steel needle strongly magnetized, instead of the soft iron plunger. You may take a piece of No. 22 gauge pianoforte wire (it is No. 22, I think, or thereabouts) 11 cm. long, and temper it glass hard. Hang it by a little loop of thread well tied on to its upper end. (Don't be at the trouble of getting it bored.) Try if the coil itself suffices to magnetize it. It would need to be drawn through and through several times, with the full current that house 86 volts give through the coil. Try if you can get it any stronger magnetized by the Ruhmkorff or otherwise.

The chief things to find are: (1) whether there are variations in the force dependent on immediately previous stronger currents, or on lifting up the needle or letting it down, or vice versa, with a constant current through the coil. (2) Whether an accidental reverse current would demagnetize or reverse the magnetism in the lower part of the needle. (3) If so, can it be reinstated so as to give sensibly the same force by sending the current in the proper direction (or an extra strong current in the proper direction) and moving the needle up and down? (4) Does the magnetism remain constant enough from week to week or indefinitely, for ordinary use of the appliance as a current meter? . . .

Yours truly,
WILLIAM THOMSON.

(8) DRUID'S CROSS,
WAVERTREE, LIVERPOOL,
December 30, 1888.

DEAR MR. MACLEAN,

I want ber′ q and bei′ q for several values, say $q = 2, 4, 6, 8, 10, 15, 20, 30$ (also ber and bei for 15, 20, 30). For 2, 4, 6, these might be calculated by the ascending series. For $q = 8$ and higher values, the semi-convergent series should be used. I see that they can be much simplified from the forms we have been using: thus

$$\mathrm{ber}\, q = r^{-\frac{1}{2}} e^{r/\sqrt{2}} \left\{ \cos\left(r/\sqrt{2} - \frac{\pi}{8}\right) + C_1 \cos\left(r/\sqrt{2} - 3\frac{\pi}{8}\right) + C_2 \cos\left(r/\sqrt{2} - 5\frac{\pi}{8}\right) + \ldots \right\}$$

C_1, C_2, etc., denoting the same coefficients as before with similar transformations for bei q. . . .

Yours,
W. THOMSON.

(9)

The following two post-cards from Largs:—

January 4, 1889.—We forgot that the coefficients which I denoted C_1, C_2, etc., involve r^{-1}, r^{-2}, etc. Hence the expressions which you have found for ber′ and bei′ are only approximately for such large values of r that dc/dr, etc., can be neglected in the formula

The best way of finding ber′ and bei′ for the values of $r =$ or > 8 will be by taking

$$\frac{d}{dr}(r^{\frac{1}{2}}), \frac{d}{dr}(r^{\frac{1}{2}}C_1), \frac{d}{dr}(r^{\frac{1}{2}}C), \quad \text{etc}$$

January 5, 1889.—I see that

$$\frac{\text{bei′ ber} - \text{ber′ bei}}{\text{ber′}^2 + \text{bei′}^2} \qquad (1)$$

approximates to $\sqrt{2}/2$ when q increases to infinity. When $q = 4$ your result makes it 2·378 ÷ 3 or 0·793. So that for values of q above 6 the quotient (1) has only to decrease from 0·79 to 0·7. I think, therefore, a fairly good table and curve for (1) with q from 0 to 6 will be practically almost enough. It will be better in drawing the curve to take (1) without the factor $\frac{1}{2}q$, as the approximation to the horizontal asymptote will make it a very simple affair.

(10) LARGS,
August 31, 1890.

DEAR MR. MACLEAN,

There seems to be something wrong in the Tables. The figures marked in red in one of the papers I enclose gives

$$\frac{\epsilon^x - \epsilon^{-x} + 2\sin x}{\epsilon^x + \epsilon^{-x} - 2\cos x} = 2{\cdot}553 \text{ for } x = \tfrac{1}{4}\pi$$

and $\qquad = 0{\cdot}5114$ for $x = \frac{1}{8}\pi$.

These agree with what is given in the final table with the curves; but not with what I expect for small values of x. The other paper which I enclose does agree with what I expect for small values of x; and the blue-marked figures in it *do not* agree with the 2·55 and the 4·511, so far as I can see just now. I am, however, sending off the curves and table; but I write hurriedly to you to ask you to look into it, and make sure of them, or see if any correction is needed. If there is any it would affect the curves sadly; but I hope it is not so.

You might also go over the table for the four curves and get a few intermediate values, so as to make a more complete table, and better curves for my Phil. Mag. paper, which should be more full and perfect than anything we can get ready for the B.A.

I shall also want $x/2 \times$ the y's of all four curves for the Phil. Mag.

Yours truly,
W. THOMSON.

(11) LONDON,
May 7, 1891.

DEAR MR. MACLEAN,

I am much obliged for the results of the electrolytic heat experiments. They are most important. You might continue, as soon as may be, experiments of the kind, putting a copper electrolysis cell into circuit with the others, and the single Smee and double zinc cell as at present, all three in series. All three cells to have as nearly as may be the same volume of liquid, and the same area of plates. . . .

Yours truly,
W. T.

(12) CAMBRIDGE,
May 18, 1891.

. . . Weigh all the three zinc plates, and the copper plates in the electrolytic heat experiments. I think you will find that hydrogen is *not* deposited on the zinc plate in the two zincs cell: which will be very remarkable considering that you began with mere dilute sulphuric acid. I want a rough estimate of the heating effect in one of the cells, that would be produced simply by the dissolution of the quantity of zinc which is dissolved, with evolution of hydrogen, and no external work or electric current.

Yours truly,
W. THOMSON.

In the summer of 1891 I was giving a course of lectures on Alternating Currents, and in working out the case given by Kelvin in his 1853 paper I obtained results different from those on p. 547 of his vol. 1 of reprints, and I wrote him that the denominator of γ_1 should be $\sqrt{C A}$. He replied:—

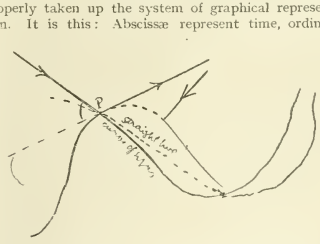
(13) LONDON,
June 30, 1891.

. . . Much obliged for your correction of γ_1 in p. 547. As it stands it is clearly wrong, as it makes $\gamma_1 = \infty$ when $K^2/4\,A^2 = 1/C\,A$. Get your correction written into any copies of vol. 1 which we have, and you might have it corrected also in the University Library copy. If you have any other corrections, keep a memorandum of all and I shall have a slip of corrections printed for copies to be given out from the press for sale. Thanks for the harmonic curves.

(14) LARGS,
July 20, 1891.

DEAR MR. MACLEAN,

The geometrical construction in your diagrams seems correct. I suppose you did it wholly by construction and without calculation. But you have not properly taken up the system of graphical representation. It is this: Abscissæ represent time, ordinates



represent distance of either body from the equilibrium position of the vibrator. Thus every arrow on a straight line representing uniform motion of the free particle must be right-wards. Your left-ward arrow-heads imply a change from right to left in reckoning the time:

but then what we want to know, which is the state of things *after* the collision, is not shown in these curves.

Beginning afresh, in every case use full line to represent actual motion and dotted lines to represent ideal continuation.

Try some cases such as this: the dotted lines to right of P representing the continuation of the motions after the collision as if there had been no change. The full lines represent the actual motions; those on the left of P being the motions before collision. The dotted lines to the left of P represent motions before the collision which if continued without change would be the actual motions after the collisions.

I am keeping your drawings because I can make out part of what I want from them, but I think you will understand, without them, what I mean about the faultily placed arrow-heads.

Continue the graphic representation after a collision till the straight line cuts the curve of sines, as it will do a second time in certain cases. Go through the proper construction for the point of intersection and you will find the graphic representation of the motion after the second collision. You will find in some cases third and fourth and more collisions. It will be an exceedingly interesting thing to have the graphical history of a multiple *chattering* collision.

Yours truly,
W. THOMSON.

(15) LARGS,
September 29, 1891.

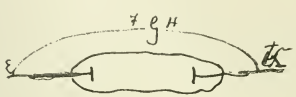
. . . I shall be much obliged if you will look among my R.S. Transactions for C. Niven, vol. 1881, p. 307, and Lamb, vol. 1883, p. 519, and have them ready for me to see on Wednesday evening. Will you ask the laboratory corps in time, to arrange if convenient, to remain till 6 or 7 p.m. Wednesday evening, so that I may have some time with them for looking into all that is going on, not so hurriedly as if they were leaving at their usual times.

Yours truly,
WILLIAM THOMSON.

(16) (GLOUCESTER READING) In train,
July 20, 1892.

DEAR MR. MACLEAN,

I am sorry not to have been able sooner to answer your letter of the 16th regarding electrolysis in secondary circuits. Writers who give $-E/R \times M/S$ and $+E/R \times M/S$ for the "quantity set in motion" must either have thought of a secondary circuit completed by metal, or not have thought much to the purpose on the subject. But it is well known that when there is a non-metallic gap in the circuit, whether of air at ordinary pressure, or at much reduced pressure as in vacuum tubes, the *break* impulse causes a flow in one direction, and the *make* causes either no flow or a much less flow in the opposite direction; because the short intense impulse of the former breaks down the resistance, while the comparatively long and less intense impulse of the make either does not break down the resistance at all, or only does so to a much less degree; so that the effective resistance is much greater in one direction than in the other. The best thing, I think, for you to do just now would be to try electrolysis in the secondary circuit just as hitherto, but by reducing the spark gap (with no vacuum tube but only an air gap) until you come to metallic circuit, except in your electrolytic vessel.



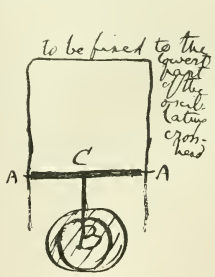
Also you might try a vacuum tube, as hitherto, and a copper wire shunt E F G H K with a spark-gap G. Reduce the interval G until sparks begin to pass. Then reduce it further till you arrive at metallic circuit, by metallic contact at G. Having felt your way by quick trials, fix on one particular distance of interval G and take another, then another shorter, and finally metallic circuit.

Yours truly,
KELVIN.

(17) LARGS,
July 31, 1892.

DEAR MR. MACLEAN,

Please get a little "compound pendulum" made, to be substituted for the ivory ball with the



shortest thread we had. You may take the, or one great, ivory ball for it, and keep one for the longer thread. . . . A A is a stout shaft. B C is stout and well fixed to the ball and to the shaft. The shaft has shoulders and the inner ends to serve as pivots. It must be free to go round and round. With proper speed of your handle we shall cause it to go round and round, which will be a beautiful experiment for Edinburgh.

Yours truly,
KELVIN.

(18) LARGS,
September 9, 1892.

. . Please arrange as soon as may be to have a thorough and prolonged trial of the gas engine, with brake to measure power for the speed or speeds we want most of for the dynamo; measuring the gas used, of course. . . .

(19) LARGS,
September 11, 1892.

DEAR MR. MACLEAN,

I shall be up again in Glasgow before long, and we can then look into various affairs; among them your work already done on the lunar orbits, to see if we can help towards the question of stability by it, or what more must be done for the question; also to examine the difference of results for cases of revolution in contrary directions; also to consider whether we shall look for orbits with four crossings, or six, or larger numbers instead of the two we have already.

I am simply striking out the last four lines from the proof, which leaves all right, but does not explain your initial numerical assumptions (where the $3x^2$ is taken and the other corresponding corrections made). This we shall do for ourselves, when we consider the relation of the orbit we have, with Hill's ovals and his cusped orbit.

Yours truly,
KELVIN.

(20) LONDON,
September 6, 1893.

DEAR MR. REID,

Please make 24 squares of zinc, each prepared as follows: keeping one side dry, moisten the other side with dilute sulphate of copper till it becomes coated either with powdery or with continuous metallic copper. Then wash with water till all the sulphate is cleaned off, leaving the powdery or metallic copper sticking to the plate. The other side of the plate should be well cleaned with sand-paper so as to present a clean metallic zinc surface. Make it up into a pile with pieces of indian rubber of the same size as those you made for the first pile. Send to Mr. Maclean in the Laboratory to be tested in the same way as he tested the first pile, warning him not to disturb by rubbing or otherwise the copper coating whether it is powdery or metallic. . . .

Yours truly,
KELVIN.

(21) LONDON,
September 8, 1893.

DEAR MR. MACLEAN,

I was much obliged for your report on the new piezo-electric pile. I have asked Mr. Reid to send you a newer one for trial. I suppose you received it this morning, and would know what to do with it.

But N.B. in your trials of the first, there must have been a shred or shreds between copper and zinc. The electrometer ought always to remain quite steady at its metallic zero. After you join the two electrodes metallically, get the needle to rest at zero, and disconnect them. The wandering you found must have been due to shreds. Try to get quit of shreds in your new trials. Look for them with microscopic eyes. Clean away what you can with a slip of metal or otherwise, brandished about through the air space. If you don't succeed with all the 24 plates, try with a single pair; get the electrometer quite steady when it ought to be steady. Then with the two wires disconnected apply pressure and diminish the distance below the plates, etc., etc. Let me know, by post, what you find in trials for steadiness.

Keep the lowest plate always uninsulated and connected with the outer case of the electrometer, and with one pair of quadrants, and the uppermost with the insulated pair of quadrants.

The new pile is to let me see if electrolytically deposited copper (rough or smooth, partially oxydized or metallic) will serve instead of sheet copper and save expense in soldering, in a model I think of making with hundreds of pairs, for illustrating the molecular constitution of a crystal.

We have had a very interesting time in the House of Lords, to come to an end this evening, and we leave to-morrow for Aix-les-Bains

Yours truly,
KELVIN.

(22) AIX-LES-BAINS,
September 14, 1893.

DEAR MR. MACLEAN,

I thank you for your letter of Monday describing your first experiments on the new piezo-electric pile. They answer, sufficiently I think, and in the negative my main question, which was—*will electro-deposited copper serve as well as sheet copper soldered to the zinc, or fairly well at all events.* You might, however, try farther (a single pair will do), and by washing carefully and then drying by heat, you can get the coppered zinc to serve tolerably well comparatively with copper plate soldered on. Perhaps if you heat it to quite a high temperature, the electrolytic copper may be brought to a condition to work well. Indeed, if it is oxydized by heat, I think it ought to be as strongly electro-negative as oxydized sheet copper. But perhaps there is too great a mixture of zinc, in some form or other, with the deposit, to let this be the case. What was the appearance of the deposit? Was it like metallic copper, or was it black and powdery?

The *great* effect which you observed on taking off the glass rod after heavy pressure is, I think, undoubtedly due to contact electricity of separation between glass and the solid which it touched. In further experiments let the lower end of the glass rod press on polished zinc or copper. Increase and diminish the pressure without removing it from contact.

You will see by the printed slip that I anticipated trouble from a movable glass rod, and described a way of experimenting to avoid it. But there may be trouble from previous electrification of the weight and from contact electricity between the lower surface of the weight and upper surface of the pile. I have asked the

Secretaries of the B.A. to send you the first pile as soon as my paper has been read; so I dare say it will reach you by Saturday or Monday, or at all events not many days later. You might try it, *first making sure* of perfect enough insulation, and *no disturbance by electrolytic conduction of shreds*. You may still use the glass rod, as the readiest way to apply the pressure. I shall be glad to hear from you how you get on with this and other affairs.

Yours truly,
KELVIN.

(23) AIX-LES-BAINS,
September 20, 1893.

DEAR MR. MACLEAN,

I thank you for your letter of the 18th. I think you will get good results with the first pile, if you get absolutely quit of shreds, and have good insulation; so that when the connections are made between the electrometer and the top and bottom of the pile the needle remains at metallic zero after the fine wires have been connected and disconnected; and remains at a constant deflection, if, anyhow, you give a small charge to the upper plate and leave it to itself.

When you disconnect the fine wires, after getting metallic zero, there should be no jump. If you then find a slight deflection as you did before, clean the wires carefully, at the place where they are brought into contact and try again.

Take away your upper glass plate, it can only produce disturbance and may produce large disturbance. Apply the force by increasing the pressure of a round-ended glass rod, like the one shown in your sketch but pressing on clean polished metal instead of on glass. Varnished glass rod, or a little rod of vulcanite would answer perfectly provided it insulates so well as not to cause any perceptible increase in the rate of subsidence from a small position or negative charge given in any way.

Put the new storage battery which you saw in my study into hands for testing for capacity in the usual manner. Charge it with the usual charging voltage per cell. Measure from time to time the charging current and voltage so as to get fairly accurate time integrals of the charging current and of the charging electromotive force reckoned in volts. Do the same in discharging so that we may get a fair estimate both of quantity put in and taken out; and of energy put in and taken out.

Will you tell our servants we shall be home on the 10th October, please.

Yours very truly,
KELVIN.

(24) LONDON,
April 24, 1894.

DEAR MR. MACLEAN,

I have been writing an introduction to our paper, and I enclose it with your MS. as this would perhaps be the most convenient way to let you add some of the additional information which we want. In Fig. 1 show the outside case of the electrometer connected by metal to the roof. Add 2 or 3 tables to pp. 12 and 13 of your MS. as now numbered by me, and make amendments which occur to you to prepare it as nearly as may be for press. A little insertion is, of course, necessary between the last of mine and the beginning of yours, but we can easily manage that when we get the substantials written. I suppose you will be able to return it all to me in the course of a few days.

Yours truly,
KELVIN

(25) LONDON,
April 25, 1894.

DEAR MR. MACLEAN,

Lord Kelvin thanks you for yours of yesterday. You have answered some of the questions of his of yesterday so you will, of course, not trouble further about them. He is delighted to receive the report about the cloisters' experiments and thinks this also should go into the present paper. He would like to know whether the negative terminal of the machine does not apparently give less electricity, and would be glad if you would try this with a Leyden jar instead of the fine points and whether with the same number of turns of the machine you find any difference from the two terminals.

Yours very truly,
THOMAS A. B. CARVER

(26) LONDON,
April 26, 1894.

DEAR MR. MACLEAN,

Thanks for the two copies of your three papers, which I received yesterday evening. In our present paper on electrification of air we must omit the statement that "recent experiments in the new college prove negative electrification to be the ordinary natural condition."

I think you should repeat observations without any lamp, and using instead a scale illuminated by daylight and the image of it viewed by a convex lens. You understand the system, I believe, and know that it is preferable to the telescope which has hitherto often been used. The observations within doors described in your Phil. Soc. paper were, I suppose, all more or less vitiated by the paraffin lamp used. Without multiplying places of observation inconveniently, we must try to get a decided answer as to the ordinary condition of natural atmospheric air, say under the cloisters as at present, in the top room of the tower, and in the Bute Hall.

At the beginning of our observations last December I think we found results as to electrification by the water dropper similar to those described in pp. 500–1, Phil. Mag., 1890; and the negative electrification by water ceased to be observed after some time, as we believe, because of the air becoming more and more free from dust. Did you find again the negative electrification by the water after you introduced smoke some weeks ago, and has this effect again ceased when the air has become more pure?

Mr. Carver adds something about the portable electrometer which arrived safely this morning.

Yours truly,
KELVIN.

(27) LONDON,
April 28, 1894.

DEAR MR. MACLEAN,

Lord Kelvin desires me to ask you to send a very small phial of prepared sulphuric acid for charging the pumice of the portable. Also to look and see if there is a curb sender in among the apparatus and a punching key. If there is, will you look it out and send it down to White's for examination and repairs, if necessary, and in any case let Lord Kelvin know what you have done. If there is a third quadrant electrometer in the Laboratory, will you send it to Mr. Reid for fixing on an arrangement for magnetic control when used with a unifilar suspension. Do not send the one with the brass lantern as this would not do for applying the ring of the arrangement to, and, if necessary, substitute this one for one with the plain bowl which you have in use.

Yours sincerely,
THOMAS A. B. CARVER

(28) LONDON,
May 3, 1894

DEAR MR. MACLEAN,

Read "Electrostatics and Magnetism," xvi, §§ 299–300. The inference was that the lower air in ordinary fair weather is negatively electrified out of doors. Your observations at the staircase and entrance to the Bute Hall thoroughly corroborate this; because the air there is a sample of the natural air out of doors, and the electric screening against influence from the higher atmosphere is practically perfect there. It seems as if under the cloisters, and especially in the neighbourhood of the staircase, the electric screening was not sufficient to perfectly prevent the effect of the distant positively electrified air of the higher atmosphere from producing positive potential at the water dropper. I would like to make quite sure of this. Look if you can see sky from 5 ft. above the ground under the cloisters, and judge what the condition is 15 ft. above the ground. I think you had better get a plan made of the floor and roof with fair, not extremely minute, accuracy. It should show two sections of the roof E. and W. and N. and S., and the position of the electrometer, and the position of the water dropper, with dimensions fairly accurate.

I think you might try the air in the room above the Logic and Greek class-rooms in the N.W. wing, making arrangements when you can to find the effect of draughts of air coming in from the outside, which, at all events when there is wind, you may very readily do. But remember opening a window immediately undoes part of the screening and tends to produce positive potential at the water dropper, even though the incoming air is negatively electrified. The air in our apparatus museum and in the proposed upper class-room in the N.W. wing is not subject to any electrifying influence, and if it is found negative this seems to me to prove decidedly that the natural air outside is negatively electrified, but we want to make quite sure of this. I understand that all your new observations are made without a lamp and that the readings are by lens or by a telescope. Tell me how this is. We may perhaps find the Logic or Greek class-room preferable to the one above that, but judge this for yourself.

Try the effect of opening a window while doors are closed. Then open the doors to allow a draught to come in by the window to see whether this makes a change. We want to eliminate the effects of variation in the screening. But I should have thought the screening practically perfect, even when a window is open, if the electrometer is 2 or 3 yards from it and cannot see sky out of it.

For our present paper could you not give a better specimen of the positive and negative electrification showing a longer series of observations than that represented in curves 1 and 2, which I return? Curve 2 is very meagre, breaking off after two minutes and a quarter. I would like to show the result both of positive and negative electrification for an hour or 32 minutes, or at least 16 minutes. Look up your records and see what you can do in this respect. The horizontal scale in the diagram might be $\frac{1}{4}$ or $\frac{1}{8}$ of that of the curve returned so as to get 16 minutes or 32 minutes into the same compass.

Leave margin on your letters for remarks, and in plotting results reduce the readings to volts and put these on the curves, which should be on one side only of the paper.

Yours truly,
KELVIN.

(29) LONDON.
May 18, 1894.

DEAR MR. MACLEAN,

I send you a first proof of our paper. I am afraid it will need corrections in respect to the queries pencilled in § 2. On this account I am anxious to hear as soon as possible if anything more has been done in the Logic class-room.

I wish very much to know whether on several different days and different times of day you still get the nearly zero result which your first observations gave. I am adding to the paper a short statement as to absolute value of the electric "volume density" in the air of the vat proved by the observations given in the paper. . . .

Yours truly,
KELVIN.

(30) WITHAM, ESSEX,
May 21, 1894.

DEAR MR. MACLEAN,

One thing more for our paper: a statement to the effect that when the vat, after the air in it had been electrified, was left to itself *with water dropper not running* it kept the electrification [? better than with the dropper running ?]. A short circumstantial statement [? telling whether the electrification is kept better or not better than with dropper running ?], and giving, not perhaps in a table, two or three numbers expressing results, would be an important addition. I think it might include what we found when it was left all night undisturbed. If you can write me by to-morrow's or

next day's post I shall be glad to have it, and get it into the printed proof in time for the communication to the R.S., which is to be at the meeting of Thursday week. I am hoping to hear something from you here to-morrow, telling more of natural electrification of indoors air. Meantime, I am correcting § 2 on this point, in accordance with what I heard from you up to Friday last.

Yours very truly,
KELVIN.

(31) LONDON,
June 2, 1894.

DEAR MR. MACLEAN,

Will you thank Mr. Galt, Mr. E. Murray and the others for the reports which I received this morning. I had only time to look into them very hurriedly before leaving for the Visitation of the Greenwich Observatory. But I just saw that the air in the Logic class-room seemed generally small positive and in the Moral Philosophy negative. We must try to learn something, if possible, as to the causes, but I think it seems proved well that there is much less of electricity in the air than I used to find in the old College. I think you might try the Bute Hall again; also the top of the staircase beside its north door. I think you still had the lamp at your last trials there. At all events, it will be well to try it there in altered weather; also again under the cloisters. I was sorry not to see the direction of the wind and the character of the weather marked on the reports and curves which I received this morning. Can you get this? . . .

Yours truly
KELVIN.

(32) LONDON,
June 20, 1894.

DEAR MR. MACLEAN,

I thank you for your letter of this morning, and I am glad to hear of such good progress in your course for medical students.

I am afraid you will have little time for more experimenting now, but if you find you can do so conveniently, you might start some trials to test whether water condensing from air carries away electrification with it.

Take a U tube of glass of about 1-in. or $\frac{3}{4}$-in. or $\frac{1}{2}$-in. bore, each branch about 18 in. long. To secure insulation in the upper 8 in. of one of the branches, varnish it carefully inside and outside with clean shellac varnish, and get it well dried. Into the other branch fill broken fragments of pumice previously well moistened with strong H_2SO_4. Fix the upper end of the insulated varnished branch to a support which need not be insulated. Surround the whole by a metal screen, which may be a piece of stove pipe or even four vertical sides of tin or other sheet metal, enclosing all as in a box. Connect the top of the pumice by some fine platinum wire to the insulated electrode of a quadrant electrometer; and for economy of wire and avoidance of disturbances in the air, bring the whole apparatus as close together as possible. Connect the case of the electrometer to the metal screen. Connect an india-rubber tube to the end of the insulated branch and blow a large quantity of air through. It is possible that the dried air in escaping may leave positive or negative electricity behind it with the water which it gives up to the H_2SO_4, but I am by no means confident that we shall get any result. Still it will be knowledge gained if we find that we get no electric effect.

Yours truly,
KELVIN.

(33) LONDON,
June 28, 1894.

DEAR MR. MACLEAN,

I am much obliged for your letter of yesterday. It shows a possibility of a very important result though perhaps not much probability. If the result really is electrification by absorption of water from the air, the experiment so far absolutely proves that with the present apparatus and speed of blowing very high insulation will be needed.

If you have got time to have the experiment repeated, try the insulation for at least 10 minutes. It might have been better to support by a fixed, uninsulated cross-piece at the varnished top of the U tube, but if you have got it quite satisfactorily hung by the india-rubber pipe, let it be so. In repeating the experiment test by alternately blowing for half an hour and not blowing for half an hour. Repeat the insulation test often enough.

Yours truly,
KELVIN.

(34) LONDON,
June 30, 1894.

DEAR MR. MACLEAN,

How did you like the altered quadrant electrometer when it came back from White's with the magnetic adjustment? Did you find you could vary the sensibility conveniently, and between what limits could you do so? I think it will be found a much simpler and better arrangement than the bi-filar, but I would be glad to hear what you think of it before deciding to have the other quadrant electrometers in the laboratory altered, which I think I would do if the new arrangement proves decidedly successful.

Yours truly,
KELVIN.

(35) LONDON,
July 3, 1894.

DEAR MR. MACLEAN,

I am much obliged for your letter of yesterday. I am glad the magnetic adjustment is so satisfactory with the quadrant electrometer. We must have them all altered accordingly, but I shall see to this myself when I get back before the end of July. . . .

Yours truly,
KELVIN.

(36) LONDON,
July 11, 1894.

DEAR MR. MACLEAN,

I was delighted to receive your letter of the 6th and to hear of the very remarkable result you have got by blowing air through the U tube. If confirmed, it will be exceedingly important. How long time did it take till the reading went up to 8 or 9 volts? Are you quite sure that it was positive? I would like as soon as may be the same experiment tried with pumice moistened with water instead of with sulphuric acid. This would be decisive as to whether or not the result already got is due to taking water out of air. . . .

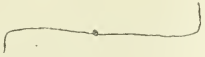
Yours truly,
KELVIN.

(37) HAYWARDS HEATH,
July 15, 1894.

DEAR MR. MACLEAN.

I am glad you have been able to put the U tube arrangement into Mr. Galt's hands to make the experiment with pumice moistened with water, instead of sulphuric. If we find no effect, or negative instead of positive, with water the result you got before leaving will be established as a very important discovery, and will be a splendid subject for a communication to the B.A.

I think it will be better to defer the electric wind experiment till we get the circumstances better defined than hitherto, and some experiments with varied cir-



cumstances. I was going to write to you to have an experiment tried with the old apparatus hung up by a fine torsion wire, over a large horizontal metal plate connected with earth, but I saw there was no time till after your holiday, without postponing the much more important experiment to try for electric effect of absorption. We must also vary, and make more definite, the circumstances of the experiment showing pressure of electric wind on the suspended plate, by placing metal connected with earth all round the point, and the air current (* see below). As last arranged, the influence of the earth, to which the origination of the electric brush, and wind, is due, is too indefinite. If you had metal in metallic connection with the point, and movable plate all round, there would be no brush and no electric wind. We must try metallic plates [*] connected with the earth, in various positions beside the point, as well as all round, as proposed above. Even the result we have already got is interesting, but it will be much more interesting if we defer publishing till we have some further experiments.

A short time ago I found with the portable electrometer which I had sent to me to London *an enormous* difference between the discharging power of the match according as it was positively or negatively electrified (I forget which way it was greater). You may remember we tried for this in the laboratory last December, I think, but got no result, as we were foiled by bad insulation. This should or may be included with electric wind, in respect to differences between positive and negative.

. . . . . .
. . . . . .
. . . .

Yours truly,
KELVIN.

(38) GLASGOW,
April 17, 1895.

DEAR MR. MACLEAN,

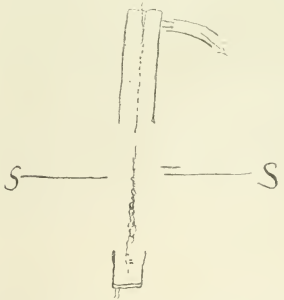
Lord Kelvin desires me to thank you for your letter of the 15th, which he received this morning. He wishes you, when you are on the west coast of Skye, to take readings (portable electrometer) with a west wind blowing on shore, and also with a wind blowing off the shore to see which (if any) gives an increase of fine weather positive electrification. You may find it difficult to get a day on which a west wind is blowing, as of course you have not control of the winds, but anyhow Lord Kelvin would like this especially if you can manage it. . . .

Yours truly,
JOHN GRAY.

(39) LONDON,
April 23, 1895.

DEAR MR. MACLEAN,

I thank you for your letters and observations of atmospheric electricity, which are very interesting, particularly those showing negatively electrified air in the neighbourhood of waterfalls. It will be particularly interesting also if you find effects of sea spray or



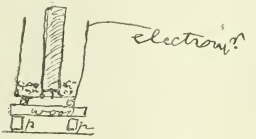
of wind blowing from the sea, compared with wind from the shore, at the same place of observation.

I arranged before I left for farther experimenting with the large funnel, as you will see and Black will tell you. You may first try drawing air from the upper

exit pipe, when a jet is shot down through the upper part of the funnel, fixed as high as Black could fix it, and with the receiving bucket as low as possible. Vary by drawing air from the inside of the receiving bucket, hung at different depths below the mouth of the funnel. Again place a paper or other screen S S to guard against air being wafted up from the bucket to the mouth of the funnel, in the trial with the suction tube at the top.

I think it will be advisable to try a very high fall later; with the whole funnel mounted beside the railing above the lecture-room table, and a quadrant electrometer mounted on a table on the upper floor; but we shall judge by what you find with present arrangements.

We must get a good trial for electricity of evaporation; this, I think, should answer. Get a good-sized milk-



can, not *too* large, insulated as shown in sketch by three paraffin blocks, with a wooden board laid on them; three small wooden knobs on the upper side of the board and the can resting on them.

The can is to be filled with boiling water to begin; and an iron heater (the heater of a tea urn, or a clock-weight would do) to be placed resting on sand (well washed) in the bottom of the can. When the heater is put in red hot, or hot enough to keep the water boiling, you will, no doubt, get a strong electric effect: but I want to see if you get an effect by rapid evaporation without boiling. [N.B.—the air space between the can and the wooden board is to prevent the board from being so much heated as to melt the paraffin blocks below.]

You have heard from Gray the tests I want, both for my own electrometer and of the one from Kew. He is to bring them both with him to me here. You might, with Galt's assistance, make the tests to-morrow or next day; and let any new students, if there are any, stand by, and learn, and help when they can.

Yours truly,
KELVIN.

(30) LONDON,
May 11, 1895.

DEAR MR. MACLEAN,

By my telegram you would see that I want some more explanations regarding your report of yesterday.

In what respect did the 3–38 experiment differ from the first four ending 12–17? Can the great differences between the five experiments have been due to the different potentials produced by the machine?

Had you begun in yesterday's experiment to stop the ingress of the gas after the extinction of the flame and before working the pump?

Make experiments in which you commence the pump one minute, and two minutes, and three minutes (or, judging according to the results which you find) longer times, after the extinction of the flame. Do this both with positive and negative electrification.

Have you found any sensible heating in the draw-off tube, or in the electric receiver?

What size of inlet pipe had you and how was it placed? Henceforth stop it at the moment of extinction of the flame with a wet india-rubber cork and keep it stopped to the end of the experiment. The 10 strokes of the pump will not draw up the water too far inside the bell, but be ready to pour in more water outside if necessary to prevent air from coming in under the lip; and arrange to prevent inconvenient overflowing when you open the ingress pipe again and let the water down in the bell.

Have you got the metal cap fixed quite airtight on the top of the glass? You must have this done if it is not already tight and right in all respects. It promises to be a most important piece of apparatus.

We shall use it with Hydrogen and Oxygen and Carbonic Acid Gas, with electrification by needle-points instead of by flame, possibly also with hydrogen or coal gas or Carbonic Oxide instead of air and with a jet of Oxygen or of common air to give a flame; but there would be some arrangement required to light the flame if we do anything of this kind.

Please tell Mr. Galt that I would like the experiments with the combustion tube to be made more decisive as to difference, if any, between positively and negatively electrified air; and to try if there is any electrification by the heat itself without any electric machine, but simply drawing air from the outside through the canister, etc., or direct from the laboratory, into the combustion tube. Try this first simply with the empty glass combustion tube and afterwards with a quantity of clean bright sheet copper, placed in the tube to see whether oxidation of the copper gives electrification.

The same might also be tried with little lumps of charcoal in the tube, well freed from dust, the charcoal having been previously heated in a crucible to make sure of it being perfectly charred.

Mr. Galt had better not dismount anything at present for the experiment upstairs of which Mr. Gray wrote yesterday, but we must keep this in mind to do it as soon as we can without losing the opportunity to work with the apparatus as at present installed in the lower laboratory.

As soon as the combustion tube experiments are done I want the funnel and water jet to be used as a source of negatively electrified air for experiments on tubular filters, and perhaps we may arrange for jets of salt water to give us positively electrified air.

Thank Mr. Galt for his letter of yesterday received a moment after last sentence was written. It confirms the want of knowledge of the cause of the difference between positive and negative in the high temperature experiments.

It looks as if there really is positive electrification produced by the heat.

Yours truly,
KELVIN.

P.S.—For trying filters on Tuesday or Wednesday, or when Mr. Galt has done with the combustion tube experiments, use the funnel (whose length) with a bottom

fixed in slightly inclined (need not be soldered), so as to be battered by the drops from the jet, and let the water flow away, or fall away in large drops by an aperture at the lowest part of the inclined disc, the lower part to be fixed at M M as before. You may lower the whole to the most convenient position.

Make two or three comparative experiments on the electrification of air drawn from the lower exit tube; but in all probability choose the upper one, and keep the lower either corked or open, for our regular experiments on filters and diselectrification by shorter or longer tubes, etc. I shall explain this on Monday or Tuesday.

(41) LONDON,
May 17, 1895.

DEAR MR. MACLEAN,

The experiments described in Stewart's report of May 15th are very interesting; but why did you stop short with the 2 minutes' interval? There is but little difference between the results with the 2 minutes' interval and the 1 minute interval, therefore the experiment should be pushed on to 3, 4, 5, 6 minutes or longer until you find so long an interval that all the effect is lost. Having got so good an effect for 2 minutes you had better try next 4 minutes, after that, according to your judgment, 6 minutes or 8 minutes, and so on. When you have done with these experiments I want you to try similar experiments with no flame, but with electrification by one or more needle-points, using a voltmeter and keeping as high a potential as you find you can either by the Winter or by the inductive electric machine. After that we shall try the same thing with Carbonic Acid instead of air and electrification by needle-point instead of flame. . . .

Yours truly,
KELVIN.

(42) LONDON,
May 21, 1895.

DEAR MR. MACLEAN,

Lord Kelvin says: "I want you to try different speeds of drawing off the air 5 or 10 strokes as quick as conveniently possible; and also 2, and 3, and 4 times as slow as hitherto. I wish this tried both with the present filter also with the same tube, but no wire gauze or cotton wool, also with finer and finer tubes, say 4 cm. long, with bores down to the finest you can get from White. You may use simple tubes without the outer tube I got for Mr. Galt's experiments, of which the object was to equalize the electrostatic capacity and so to allow comparison of the filtering powers of the different bores.

"What I want you to try now is to compare the filtering powers of one length and one bore with air rushing at different velocities through it.

"Thank Mr. Galt for his letter and report of yesterday with quite a wonderful result, showing the 0·3 centimetre bore to be less effective than either the 1 centimetre or the 0·18 centimetre bore.

"You may tell him, in future experiments of the same kind with electrification of air by jet through the funnel to draw from the bottom in every case with the top aperture closed. He might try smaller and smaller jets with this arrangement and see whether he can get a strong enough effect to allow him to try for positive electrification of air by a few litres of salt water poured into a funnel at the top and flowing down through the same nozzle."

Yours truly,
JOHN GRAY.

(43) LONDON,
May 31, 1895.

DEAR MR. MACLEAN,

Lord Kelvin desires me to thank you for the reports you sent yesterday and to say that he is very much interested in the results they contain. He wishes to know if you have any of the calculations you made on "chattering collisions"—a free particle colliding with a vibrating body. If so, you might send them here as he wishes to continue the calculations.

You might look in a roll of curve sheets, which is lying in the left-hand corner as you enter the door, and see if there are any curves of sines pertaining to these calculations, and send them also if you can find them readily.

Lord Kelvin also wishes the "1892 calculations" sent. They are lying in a large envelope marked "1892 calculations" among the letter books beside the copying press. . . .

Yours truly,
JOHN GRAY.

(44) LONDON,
June 1, 1895.

DEAR MR. MACLEAN,

Lord Kelvin desires me to give you the following instructions about the experiments:—

Try a stirrer in your large glass cylinder. Keep it going and keep it at rest in alternate experiments all

the time of electrification. Try the 30 seconds electrification and the longer times of electrification with all other circumstances the same as in your former experiments. The stirrer may be a large hexagon of tin plate made up of strips an inch broad and soldered together. Take care that there are drops of solder at the corners to prevent the iron from scratching the glass. The six corners should be an easy fit inside the glass. The stirrer may be moved up and down by two stiff wires soldered at two opposite inner corners of the hexagon coming through holes in the roof, made nearly air-tight by little stuffing boxes packed with wet cotton thread round the vertical wires. The person working it must take care to move the two wires equally so as to keep it horizontal.

Say to Mr. Galt that I think he should now try the long funnel in the lecture room. Fix it to the railing in proper position above the north end of the table to let the jet fall into water in the lead tank. I want to test thoroughly the question of electrification of air by drops falling through it with no influence whatever of falling against anything whether water or solid. The air may be sucked sometimes from the upper and sometimes from the lower tube, the one not used being stopped tight by a cork. The electrometer may be placed either on the lecture room table or up above, beside the railing, whichever is most convenient. The receiver may be a single tube about 10 cm. long and 1 cm. bore with 12 gauzes and 11 plugs of wool.

Lord Kelvin wishes you to look in "Cadmus" in the study, under H, and if you find a letter from the late Prof. Hertz, to send it here.

Yours truly,
JOHN GRAY.

(45) LONDON,
June 6, 1895.

DEAR MR. MACLEAN,

Lord Kelvin desires me to send you the enclosed letter from Dr. Lenard for your perusal. Please return it when you have finished, as it is not yet answered.

As you will see, Dr. Lenard wishes a copy of the late Prof. Hertz's letter to Lord Kelvin. I am sorry to have given you the trouble of hunting through (H) in "Cadmus" for it when I might have remembered that it is in the book on the "Life of Hertz" translated by Jones. This book is in the revolving bookcase.

You might please get a copy of the letter made and send it here with Dr. Lenard's letter. . . .

With kind regards,
I am, Yours truly,
JOHN GRAY.

(46) LONDON,
June 12, 1895.

DEAR MR. MACLEAN,

. . . Towards answering the still unanswered question, let yesterday's experiments be repeated with careful counting of the drops falling per minute from the lip of the funnel in every variety of the stream. Then incline the funnel somewhat so as to considerably increase the quantity of water striking its inside, and re-try a similar series of experiments. Lastly go through a similar process with the lower half of the funnel unsoldered and taken away. I thank you for your report of the 7th June. Please say what receiver you used in your experiments of June 7th for finding absolute quantities of electrification. The numbers you give me tell me in absolute value the quantities given up to the receiver per cub. cm. of air passing through it. From this we wish to estimate the total quantity of electricity per cub. cm. of air entering the receiver. We may estimate this roughly from your previous experiments on the efficacies of different receivers. As soon as you can, conveniently, try electrification of Carbonic Acid by 6 needle-points, instead of air as in the experiments already made.

Yours truly,
KELVIN.

(47) LONDON,
June 24, 1895.

DEAR MR. MACLEAN,

I was much interested in your report received this morning. Try the electric receivers with common air electrified by points and by flame, as before in your big glass cylinder. They may act very differently with carbonic acid, common air, with or without fumes of combustion, and with hydrogen, nitrogen, oxygen, coal gas, etc.: and we must try enough of different gases to form a judgment. You should not have had the $1\frac{1}{2}$ metre of india-rubber tube between the two receivers. Place them as close together as you can: that is to say, simply with a paraffin funnel between them.

Try also with air electrified by battering on the bottom plate of the long funnel.

As soon as Galt has done the salt water experiment of which I wrote to him on Saturday, get the funnel back for use in the lower laboratory and bring himself into use with you.

Yours truly,
KELVIN.

(48) LONDON,
June 26, 1895.

DEAR MR. MACLEAN,

. . . One of the chief things we now have in view is to find something of the laws according to which electrified air (or other gas) gives electricity to conductors in contact with it.

You might go back to the Winchester quart bottle and, after shaking it up well, with the hand or an india-rubber cork as stopper, test its electrification by drawing air through one of your most powerful electric receivers connected with the electrometer. Then vary by putting a paraffin stopper into it carrying a long polished metal wire (perhaps about 1/10 of an inch diameter) through the axis of the bottle down to near the water surface, and connect this wire to the electrometer. Then take metallic zero and leave all insulated to see whether the electrified air in the bottle gives up some of its electricity to the metal wire. The paraffin stopper must insulate well.

Read this letter with Mr. Galt and arrange with him to take up this and other work with you.

I have given notice of a paper probably to be communicated by us to the B.A. at Ipswich. I shall be there myself. I do not know if either of you think of being there also. I can of course take charge of the paper

Very important.

Another thing to be gone on with is the non-electrification of air by needle points after 3 or 4 minutes of maintaining 7,000 or 8,000 volts. Try your old experiment with the potential maintained steady for, say, 5 minutes, then stop the electric machine and disinsulate the needles for 2 minutes (or longer or shorter according to results). Then electrify for $\frac{1}{2}$ a minute and try for electrification by the old method.

Thus you will learn how long time elapses till the air recovers its quality of receiving electrification by $\frac{1}{2}$ a minute's electrification of the needle-points. Do this both for positive and negative electricity.

You have also carbonic acid to deal with just as you deal with air for this question.

Ask Mr. Galt to repeat the experiment of the 25th and 26th with weaker solutions of salt water and with good sea water.

Yours truly,
KELVIN.

(49) LONDON,
July 8, 1895.

DEAR MR. MACLEAN,

We are leaving for Aix-les-Bains about the 17th of July and hope to be home in Scotland by the middle of August. You might arrange about holidays for yourself and Galt and others concerned, and let me know what you think of doing. We might, perhaps, arrange to have some laboratory work going from the middle of August till time to leave for Ipswich; but don't make a point of this if you find it more convenient to have the laboratory wholly shut up at that time. We have quite enough for a British Association paper: although nearly everything we have done since April wants more or less of finish to get the best points from our work. . . .

Yours truly,
KELVIN.

(50 LONDON,
May 8, 1896.

DEAR MACLEAN,

I want to make some experiments with our siren to try to magnify the sound. You might let Black try fitting a tin tube to the siren, about two feet long to begin with, we can vary the length afterwards, and try whether the sound is greatly augmented at any speed of the siren such as our ordinary speed for the 256 puffs per second. The tube should be easily pulled off so that you can compare the loudness with the tube on and the tube off.

The diameter of the tube will just be large enough to go round the siren over all and it need not be fitted air-tight. The easiest way will be to fit a circular projecting disc of wood to the tube at the foot of the siren as shown in the figure. The end of the tin tube

will rest on this and it (the tube) can be easily slipped on and off.

Yours truly,
KELVIN.

(51) LONDON,
May 21, 1896.

DEAR MACLEAN,

I am sorry not to have been able to return the diagrams sooner and write on other things connected with the experiments as I have been very busy for the last fortnight with preparations to give evidence before the Petroleum Committee of the House of Commons in the interests of public safety. I gave the evidence yesterday and I am now somewhat freer.

Beginning with your yesterday's dispatch, I return Stewart and Templeton's leaf with remarks *for them*. You will see that their statement about pressure is not intelligible. It would make the pressure of the air after passing the platinum tube less than half the atmospheric pressure and less than the pressure after passing the brass filings filter.

The method of experimenting does not test the receiving power of the platinum tube. It shows it to be much less than that of the brass filings but gives no definite result. As soon as you can get time you should have it repeated with the platinum tube and the filings filter in series and connected to two electrometers, the absolute quantities of electricity corresponding to their quantities being known.

I now return all the laboratory reports which I have received since leaving Glasgow as it may be convenient for you to have them together with my wholly or partially answered pencillings on them.

See Mr. Galt of May 8th * 1. This is quite wonderful. It shows that charging the cylinder negatively for 15 minutes at 12,000 volts causes the air within it to be electrified positively and vice versa (positive, negative). Are we *sure* of this?

(You see I have assumed an answer to my pencilled queries at the foot of page 1.)

The only explanation I can see is that brushes must have proceeded from the surrounding earthed guard cylinder and that air electrified by them must have been attracted into the interior of the electrified cylinder. If this is confirmed it will be a most interesting and important result.

Yours truly,
KELVIN.

(52) LONDON,
June 1, 1896.

DEAR DR. MACLEAN,

Lord Kelvin desires me to acknowledge receipt of the Electrification of Air paper and to say that he has already begun to go over it. Lady Kelvin would be obliged if you would go over to the house and look in the portfolio containing the diplomas, for the letter which accompanied the order "Pour le mérite."

The information that is wanted is:—

1. The date of conferring the Honour on Lord Kelvin.
2. Whether it was the present or late German Emperor who conferred it.
3. What class is it and special occasion or reason if any?

If the letter does not contain the information you might try and get a look at the Order itself, and send the information *by return*. In any event you might send the letter which accompanied the diploma.

In great haste,
Yours sincerely,
JOHN GRAY.

(53) LARGS,
September 30, 1896.

DEAR MACLEAN,

I thank you for your letter of yesterday.

To get trustworthy results by the potential method it will be necessary to repeat the experiments with resistance of standard very approximately equal to that of the wire measured. You cannot be sure that your ratio of deflections 390/80 is within 1 per cent of being equal to the ratio of the potentials.

You might take the mho box and find on it a resistance as exactly as you can equal to the resistance of your aluminium wire, using the potential method to test equality. And test by the same method the value of the mho of the mho box according to the standard ohm.

You might see if you can get some of this done tomorrow forenoon. I shall be up at the College to lunch and shall be over in the laboratory between 2 and 3 when we can go into questions regarding our electrical experiments, particularly the measurement of currents through vacuum tubes by galvanometer. . . .

Yours truly,
KELVIN.

P.S.—I think we had better take Hospitalier's coefficient (0·00423) for reduction of resistance to zero of aluminium rather than calculating it from Dewar and Fleming.

It seems improbable that the true coefficient can be as large as 0·0054.

(54) SURREY,
June 9, 1897.

DEAR MACLEAN,

I suppose you have been able to make the experiments with electrified disc instead of point, below the paraffin or other screen, and send a statement to "Nature" making the promised §§ 10 of our article. But I wish you could also, this week or next, do the same with a much larger insulating screen: say a disc or square of paraffin 30 cm. diameter. I expect this will completely annul the diselectrifying effect.

Either with this or the paraffin screens hitherto used, you should renew the charge on the insulated metal below, several times. You will, with the larger screen at all events, find the disinsulating effect of the flame quite stopped. There will always be *an apparent* loss from the metal plate below the screen, due to opposite electrification induced on the upper surface of the screen by the electrified body below in virtue of the conductivity in the air above.

I believe this conductivity is due to invisible portions of the flame drawn downwards by the electrified body below. Hence it is that I want a *large* electrified body, and not a small steel wire and point.

You might send me Gray's MSS. account of our little experiments with the portable electrometer of last winter.

I am adding the reference to Guthrie to our present paper.

In returning Wallace's paper (which I return to you enclosed) you should tell him of Guthrie's published experiments proving diselectrification by flame, or red or white hot iron above the electrified body. You might also tell him of my earlier unpublished experiments (quite short, of course, but just for his information, and to satisfy him that we are not accidentally anticipating him by a week or two).

His and his colleagues' experiments are very good as far as they go.

You should write to Tait giving him the title of our paper, and saying you will be present to read it on the 21st.

Yours truly,
KELVIN.

(55) LONDON,
June 11, 1897.

DEAR MACLEAN,

I am glad to have the results of your experiments of yesterday. To interpret them, however, we would need to know the insulation of the electrometer without the flame burning. It looks as if the losses of positive, 9 mins. 40 secs., and negative in 7 mins. 43 secs. (10 to 12 a.m.) with the glass plate between the disc and the flame were due wholly or almost wholly to imperfect insulation of the electrometer: and that the same is to be said of the experiments from 12 to 1 p.m. after two rechargings. What do you think from your general knowledge of the insulation of the electrometer? But I hope you will succeed in getting this so much improved that, without the flame the loss from 3,000 to 2,000 would take more than an hour.

Try next week to get experiments like yesterday's done with two large paraffin plates each 30 cm. in diameter so that you may be able to include the results in the communication to the R.S.E. I shall keep back the publication in "Nature" till we get all questions settled as far as possible. I shall have to add a short statement referring to Van Riess's explanation* (1849) which you will see is the same as mine of which I told you in my last letter. It is made very difficult by Worthington's experiment.

I am much amused with the passage from "Notes

* See *B.A. Report*, 1889, p. 226

and Queries" which Prof. Young has given us. When you see him you may tell him that this illustrates how history is made.

Yours truly,
KELVIN.

(56) LONDON,
June 24, 1897.

DEAR MACLEAN,

. . . There is still something wanting which I asked for two or three weeks ago and which I marked as § 10 (see enclosed revise). It is the same as the last three sentences of § 9, but with metal* plate instead of needle-point.

I hope you will be able to do this experiment to-morrow or Saturday or early next week to let me have a statement of the result in time to get it into print in "Nature" before July 5th. It is particularly important to see whether electrification of the lower of the two paraffin plates is or is not *absolutely null*, when the electrified metal below it is a smooth plate with rounded edges. It would be very satisfactory if you can try this experiment with two paraffin plates each about 20 cm. diameter.

It should be a differential experiment: arrangements and observations exactly the same in successive trials, with the flame burning, and the flame extinguished.

It should be made not only at 3,500 volts but at much lower potentials as in § 6 with the multicellular.

Yours truly,
KELVIN.

(57) LARGS,
January 2, 1898.

DEAR MACLEAN,

. . . We come up on Tuesday afternoon to arrive at the University about 4 o'clock, or perhaps sooner. I should call at White's on my way. Have you got any more experimental results? I hope to be able to go into some long deferred electrical questions soon now: as soon in fact as I can get my R.I. contact electricity lecture out of hands.

With best wishes for a happy New Year,

Yours,
KELVIN.

P.S.—I shall take the advanced on Thursday, and the morning lecture Thursday and Friday.

(58) SELKIRK,
January 31, 1898.

DEAR MACLEAN,

I shall be glad if you will arrange to let me meet the ordinary class on Wednesday morning, and the advanced at noon the same day.

I hope you can do this without inconvenience. I find I must go to London on Wednesday afternoon (2 p.m. departure) and return Thursday afternoon. I shall take the ordinary class on Friday morning.

Yours truly,
KELVIN.

* It does not matter what metal, provided it is polished and has no edges or points.

(59) LONDON,
April 29, 1898.

DEAR MACLEAN,

I return enclosed the proof of your paper on my patents. I feel much obliged for the great trouble you have taken in preparing it.

I have made a few notes and slight amendments on the proof. . . .

I return also your diagram of thermoelectric experiments on copper. You should repeat the experiments with giving time enough at each temperature to get a perfectly steady reading.

The reading for each temperature should be absolutely definite after you have heated and cooled the apparatus several times through the whole range. I am sure you will get very interesting and important results.

I remain,
Yours truly,
KELVIN.

(60) LONDON,
May 6, 1898.

DEAR MACLEAN,

I should be much obliged if you would look for some of my molecules for crystals—small things that I could be working with in my hand and that would look well in a picture. Mr. Orchardson, who is to make a portrait of me for the Royal Society, wants to try something of the kind in my hand. A good large number of the mere round wooden beads (especially coloured) and some of the soft wax would do quite well.

I might build up a large octahedron: or any models of this kind already made up, especially of the two colours red and blue, would look very well. Or the long models, made up of beads mounted on the long thin square rods. You might let Black put a quantity of these things into a box and dispatch it here by parcel post. A few of the large india-rubber coloured balls of both colours, whether glued together or not, might be useful.

If you chance to be in the laboratory to-morrow, you might let Black dispatch them then, or on Monday forenoon or afternoon.

Yours truly,
KELVIN.

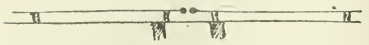
(61) LONDON,
May 19, 1898.

DEAR DR. MACLEAN,

. . . Lord Kelvin has seen Marconi and his telegraph and he has some suggestions now to make to you for your experiments, as follows:—Take for transmitter two brass rods or tubes or stoutest copper wire (to be rigid enough to be suspended horizontally by two supports, one near each end, without bending, but not heavier in weight than is absolutely necessary) These are to be suspended horizontally each on two sealing-wax supports with grooves in top for the rods to lie in, above a board long enough to take them both—i.e. somewhere about 10 ft. long. Knobs for a spark-gap, which is to be within $\frac{1}{4}$ in. long and sparks passing. The induction coil is to be placed as short

a distance as possible below spark-gap, and so as to be symmetrical.

Lord Kelvin thinks it will be best to support this board near the middle so that it can be readily turned to lie in a different direction, and also place it as high



as convenient—i.e. as nearly midway between floor and ceiling as convenient. With this apparatus in position, Lord Kelvin would like you to try experiments especially with the length of rods

(1) in the direction of transmission;

(2) ⊥r to direction of transmission;

with coherer arranged to suit to give best results. Keep the coherer in circuit with the galvanometer all the time and replace by tapping. . .

pro KELVIN,
W. C. H.

(62) LONDON,
May 24, 1898.

DEAR MACLEAN,

I have just returned from Cambridge where your letter was forwarded to me.

I think you will find the differences, according as the temperature is rising or falling, are due to the thermoelectric junction showing changes of temperature quicker than the thermometer. Probably also something of the seeming irregularities is due to the effect of stress gradually diminishing with repeated heatings and coolings.

You should try carefully now to get the law for two different metals; and, whether by annealing or otherwise, to get them brought as nearly as possible to a condition in which the same E.M.F. will always be found with the same two temperatures of hot and cold junctions.

I will be much obliged if you will find out how Dr. John Kerr is. I am afraid he may have been ill, as I did not see him at all last winter. I would like to know how he is and whether he has been going on with any experiments. I am going to propose him to the Royal Society (London) for a medal, but this is strictly private. . . .

Yours very truly,
KELVIN.

(63) LONDON,
June 13, 1898.

DEAR DR. MACLEAN,

Lord Kelvin was just in the act of dictating a letter to you just now when the time arrived for him to go off to the House of Lords; so in order to catch the post, as he will not probably be home till 6, I write now in my own name to say what he was going to say. Here is all the length he got:

"I thank you for the copies of 'Lord Kelvin's Patents,' and for all the trouble and care you have bestowed on it. I do not know the communication to R.S.E. of which you speak on 'Leakage from points and discs, etc.'"

This is as far as he was allowed to get. He intended to ask you what paper you mean exactly. Can you give this information? Dates approximately and full title. . . .

Ever yours,
W. CRAIG HENDERSON.

(64) LARGS,
October 5, 1898.

DEAR DR. MACLEAN,

Lord Kelvin will be up at the Senate Meeting to-morrow and will call in at the Laboratory.

Black would tell you that he wants to see the tuning forks for highest notes, to see if by the ear you can distinguish each note.

He also would like to see a paper by Pflüger in "Wied. Ann.," vol. 65, p. 173 (1898), and would be obliged if you would have it in the Laboratory ready for him. If you get it, please remind him to look at it.

Yours very sincerely,
W. CRAIG HENDERSON.

(65) LONDON,
June 24, 1899.

DEAR MACLEAN,

I congratulate you most heartily on your election to the Technical College. I need not tell you that your being taken from us is a very great loss to us; but I hope for yourself and for the Technical College, and for the University alliance with the Technical College, the best possible results will follow. I wish you every happiness and prosperity in your new position.

Yours very truly,
KELVIN.

Within two weeks Lord Kelvin sent in his resignation and the following letter is an answer to one of mine referring to his resignation.

(66) LONDON,
July 23, 1899.

DEAR MACLEAN,

I thank you warmly for your kind letter and for all the care and devotion with which you have worked with me and for me during these sixteen years.

I hope you are enjoying thoroughly your holiday in Skye and will return well and refreshed for your new work.

Believe me,
Yours always truly,
KELVIN.

(67) LARGS,
December 21, 1905.

DEAR MACLEAN,

I have sent you to-day a copy of my last R.S.E. paper on deep water waves. You will recognize an old friend in the picture of ship waves. My late secretary, Mr. Hunter, drew it from a new and simpler form of the equations than we had in 1887, and I lately found your old drawing, and found perfect agreement between the two.

Believe me, with best wishes of the season,
Yours truly,
KELVIN.

THE ELECTRIC LIGHTING OF ECCLESIASTICAL BUILDINGS.

By William Wilson, B.E., M.Sc., Associate Member.

(*Paper first received* 1 *August, and in final form* 28 *November*, 1917.)

Introduction.

There are few tasks as difficult as that of providing suitable artificial lighting for a church or cathedral. It involves, to begin with, the introduction of what amounts to a novelty into one of the most conservative situations in existence; a novelty which does not arise, however, from any recent innovations created by the development of electricity, and is in fact independent of electricity altogether. The disturbing element actually consists of the introduction of artificial lighting of any kind; for it is only within about the last 50 years that evening services, in the present sense of the word "evening," have been held, and it is only during that period that the absolute necessity for other than daylight has arisen. Thus the requisite fittings have had to be added either to buildings in which no provision for them existed, or to others designed exactly on the lines of their predecessors, and generally resembling the latter in possessing the same deficiency.

In spite of this handicap, the additions must be perfectly pleasing in appearance, both in themselves and also when taken in conjunction with the interior, of which they are to form a part. They have also to fulfil their practical function of affording the required general and particular illumination in accordance with correct scientific principles, which include, *inter alia*, the perfect visibility of all desired objects and the avoidance of the slightest discomfort to the occupants of the building.

It frequently falls to the lot of electrical engineers to be consulted with regard to this work. The functions of the designer are attended with conditions which are not only diverse but are of quite a different nature from those obtaining in any other class of building. The author has therefore thought that a discussion of these conditions, and a review of the various expedients that have been devised, may help to a fuller understanding of the matter.

There are two special characteristics of a church which must be borne in mind throughout: these are, first, the value placed upon economy; second, the scarcity of any form of professional attendance, and the entire absence of skilled labour.

Special Advantages of Electricity for Church Lighting.

There is no need to detail the advantages of electric lighting for general purposes over other and older illuminants, for the former are now well known even to most "laymen," and are being more and more widely recognized as time goes on. For the particular purpose under discussion, however, electricity has a number of special qualifications, the chief of which are here given as providing the *raison d'être* of this paper.

In the first place, a church is a building which is used for comparatively short periods, ranging between 20 minutes and two hours, and occurring as a rule at wide intervals. As the lights are in positions not very easily reached, the separate ignition of all in a building of moderate size is apt to be a long business for the one man usually available. It is not an unknown occurrence, for instance, for a verger to be occupied from 6 p.m. to 6.30 p.m. lighting gas burners for a service beginning at 7 p.m., involving not only considerable labour on his part but also useless consumption of illuminant. With electricity, the whole of the lamps need not be put in circuit till 7 p.m. at any season of the year, and only a portion at about 6.30 p.m., while during summer-time, at least, the whole can be switched on during the actual course of the service whenever the daylight is found insufficient. As all are finished with at about 8.30 p.m. it will be seen that a big gain in efficiency is effected under the latter conditions. Pilot lights do not provide a satisfactory alternative, as the consumption of even these small flames becomes appreciable when the main burners are employed so seldom, while the liability to failure from which they suffer is especially inconvenient in such a place.

Artificial light is occasionally called for during the daytime. A dull morning or a passing shower may so reduce the already dim "religious" daylight filtering through the stained glass, that temporary reinforcement is necessary. Considerations of economy as well as convenience favour a method which can be operated by the simple turning of a switch. The same simplicity of control permits much of the installation to be shut down during the sermon and perhaps during other periods, again securing economy, and in addition affording a welcome relief to the congregation from the brighter light necessary for reading.

One of the most valuable attributes of electricity for church work is its great suitability for concealed lighting. The absence of heating makes it possible to locate the outlets in any corner, upon any material, and in any position. The fittings may be placed at any height, as easy accessibility is not essential; and the light may be concentrated or scattered, totally or partially reflected, projected or diffused to any desired extent, by the scientifically designed reflectors and shades available to-day.

The maintenance cost of electric light for church purposes is extremely small. Leaving rare accidents out of account, only the lamps will need renewal, and that not until they have been actually "burning" for

at least 1,000 hours. Now the duty required of the principal lamps will average about five hours per week, giving a life of 200 weeks, or four years. Any other method of illumination will require renewals at intervals expressible in months, or even weeks.

Nearly all church services occur at other than times of peak load, and consequently electricity supply authorities often grant specially favourable rates to churches; but even if ordinary prices are charged, economical results will be obtained that will compare favourably with any other illuminant.

A final advantage is provided by the wide range of candle-power which may be obtained from a given fitting, thanks to the varied capacities of electric lamps available.

Requirements to be Met.

The chief problem before the designer lies in satisfying both æsthetic and practical requirements. The extent to which these are mutually conflicting may be gathered from the following examples.

Many churches are fitted with a double row of excellent chandeliers pendent from the roof, placed sufficiently high above the floor to avoid contact with the heads of the congregation. With their long stems extending from nearly top to bottom, they will harmonize to a nicety with the dominant vertical lines of a Gothic building. Thus the artistic requirements are fully met, but from the point of view of satisfactory illumination the case is quite otherwise. The lamps intrude themselves most unpleasantly between the observers and the objects of vision, and the harmful effect is accentuated by the almost general use of clear glass lamps.

Some edifices, on the other hand, are equipped with a system based on entirely correct principles, but either possessing few æsthetic qualities or to a considerable extent even disfiguring the building. In the endeavour to direct the light where it is needed and to shield it from the eye, curiously ungraceful expedients are sometimes adopted. The limit is almost reached by a suggestion the author has seen for the employment of a fitting having a strong resemblance to an inverted coal-scuttle, an object well calculated to ruin the appearance of any interior, more especially that of one of the glorious edifices provided by Gothic ecclesiastical art.

Now it should be possible to find a workable compromise between these two extremes which shall possess to a satisfactory degree the good qualities of both. It is worth while, therefore, to investigate the various types of fitting that are available for solving the problem.

Fittings for Electric Lamps.

Prior to the introduction of electric lighting, the following types were in use:—

(1) The floor-standard.
(2) The pendant.
(3) Plain lamps round the capitals of the pillars.
(4) A continuous row of lights round the top of the walls.

In any of these positions electricity is at least as effective as any other illuminant; but the second class is so superior to any of the others that these latter will only rarely deserve any consideration and will not be further dealt with.

With the advent of electricity, however, new possibilities were at once offered. Now the important advantages of electric lamps are their power of operating automatically for long periods and their ability to burn in any position without appreciable evolution of heat.

By virtue of the former, they may be located beyond the convenient reach of a lighting rod. As renewals are only required at intervals of at least four years, their bare accessibility is all that need be secured. Consequently they may be placed, if desired, at the very apex of the interior, 100 feet or more above the floor. This position is actually adopted at Southwark Cathedral, where lights are neatly installed in carved bosses at the top angle of the stone roof. At St. Margaret's, Lothbury, an excellent scheme of lighting by electroliers close to the roof has been carried out. Both these cases would have been almost out of the question if a monthly overhaul had been necessary, and impossible if taper ignition had been in vogue.

The second property enables the designer to locate the lamps deep in angles, close to or immediately below woodwork or other inflammable material, or in narrow spaces where an air circulation is impossible. It is through this that concealed lighting, so valuable when dealing with the chancel, is made possible. As far as comfort to the congregation is concerned, this method is the ideal one. By its aid, the choir or other part of the church may be lit by lamps in the recesses behind the chancel arch, on brackets behind the choir screen, in the angle behind the high capital of the chancel pillars, or in similar situations, all inclined just so that the reflectors employed direct the light where it is wanted. A neat development of this principle is to be seen in the chancel of Tewkesbury Abbey, where elongated lamps of the "linolite" pattern are ensconced in a convenient channel forming part of the wooden moulding at the back of the choir screen, and also in a similar hollow in a line of stone moulding running along the walls. This stone-work was already in existence when the installation was carried out, and is, as a matter of fact, of some antiquity. The designer merely saw his opportunity ready made, and took advantage of it; nevertheless it prompts the reflection that some similar provision ought to be made for the special benefit of the lighting. In certain cases such an addition might be well worth inserting, preferably with the concurrence of the architect, when an existing building is being wired and fitted. Somewhat similar fittings in use in the chancel of the New York Cathedral consist of long vertical strips suspended behind the pillars, and accommodating single lines of 16-c.p. lamps.

In an extreme case of concealed lighting, all the lights in the church were located on the eastward, or far side of the pillars, in groups of three to five. However, it is difficult to make this scheme a success. The conduits and necessarily squat fittings are apt to form real disfigurements to the pillars; the distribution of the light is not good, and the position of the lamps would generally be too low. In addition, the conceal-

ment would probably be only imperfectly achieved; and there is no need for totally hiding the lights. Further reference to this matter will be made later.

There remain the indirect, cove, and semi-indirect methods. The last named might be a success in fairly low side aisles spanned by a vaulting of white stone, but there are few opportunities for the employment of the other varieties, although they are not unknown in church installations. In the opinion of the author, their use is not to be recommended. The throwing into prominence of an unimportant part of the building, and the prevailing illumination of other objects than the principal ones, are not exactly artistic, and neither is the existence of a frequently rather patchy play of light on the roof.

Selection of Fittings.

To decide what fittings shall actually be adopted, first, and chiefly, the characteristics of the interior under consideration must be studied. It will suffice for a preliminary survey if the whole be divided into two portions—the chancel, and the body of the church, for it is at once evident that the character and ornamentation of the two portions are quite different. Beginning with a strong inclination to employ concealed lighting in the chancel, the designer must ask himself whether prominent fittings are required for æsthetic reasons. There will in all probability be some lighting scheme already in place, and by comparison this will help him to realize the effect of a meditated change in the directions of elaboration or simplicity, or perhaps the banishment of fittings altogether. Custom influences our ideals in this respect, and nowadays when people are used to chandeliers, often of massive design, hung low, a church interior as a rule looks noticeably bare if there is not at any rate some suggestion of the old order of things. On the other hand, many wide and not very high buildings may have their whole appearance changed from coldness to life by the addition of well-chosen electroliers. The author recently inspected a college chapel, a costly building but designed on a simple plan, there being no side aisles, transepts, or separate chancel. Candles being relied upon for lighting, the space from wall to wall was unbroken and felt bare and rather cheerless. This effect would largely have been removed by the installation of six or eight quite unpretentious pendants.

(*a*) *The chancel.*

It will very often happen that the chancel, by virtue of being more richly furnished than the body of the church, will not require ornamental fittings, and the lighting can then be entirely carried out by the concealed method. If there is a screen spanning the chancel arch, two, four, or perhaps more, short plain brackets can be mounted in a horizontal line near the top, where their presence will be quite hidden from the congregation. They should be so placed and inclined that the light is mainly directed where it is wanted, i.e. on the books and the surroundings of the adjacent part of the choir. These lamps will, then, illuminate the westward end of the chancel.

The easternmost portion can be served by lamps behind convenient pillars or other projections, at a height of not less than 15 or 20 feet if possible. It may be considered necessary for ornamental reasons to install a few electroliers, and these can then be used for the further portions of the area, subject to two conditions: they should not contain lamps of great intensity, the major portion of the lighting coming from the invisible sources; and they should be as high above the floor as appearances will permit. If there is more than one electrolier on either side, the farther ones should be stepped, or placed progressively slightly higher than the nearest. This affords a perspective effect and corresponds to the ascent of the chancel floor as it extends eastwards. At the extreme east there may be seven branched or other standards that require electrification. If so, they will add somewhat to the general illumination, which should be taken into calculation.

Roof lights may be resorted to in this part of the building, and can usually be concealed.

(*b*) *The body of the church.*

The body of the building presents a large space requiring uniform treatment. As has already been indicated, a number of alternatives are available, and it would be impossible to name definitely any one of these as the best in all cases. Something may, however, be said generally with regard to the position and nature of pendants, which, all things considered, will in the majority of cases be the most worthy of adoption.

In this regard, chief attention must be devoted to keeping the points of light out of the direct line of vision; and it is noticeable how commonly one sees brilliant lamps so placed that they inevitably obtrude themselves wherever one chooses to look, except directly downwards. At the same time it is questionable whether the other extreme is really justified, of forbidding every trace of the light sources to be seen. Fittings and shades have been designed to obviate this possibility, mostly having for their object the projection of the light forwards only, so as to be visible directly only to those who turn round and look in the wrong direction. Unfortunately, a portion of the people in most churches, those seated in the transepts, face in directions at right angles to the rest, and for them the scheme would not be wholly successful. There is no doubt, however, that such a method is infinitely preferable to the other, but one cannot help feeling at the outset that the pendulum has swung somewhat too far in the opposite direction.

The question is worth considering, whether it is not a positive advantage that some of the light sources, suitably shaded, should be visible. If one were to try the experiment of looking at a scene illuminated by visible lamps, and thus form a first-hand opinion, most people, the author thinks, would come to the conclusion that where these are well above the principal objects, are enclosed in prismatic or other good shades, and are, preferably, bowl-frosted, then the visibility is good and the eye is not fatigued, but that, on the contrary, the lights impart a cheerfulness to the scene that would be a distinct loss if they were hidden. It is generally agreed that the eye can comfortably look at a source

of light provided it is no brighter than the ordinary candle-flame. If, then, the lamps can be so covered by the shades that they are not themselves seen, and if the transmitted light is reduced to about the brilliancy of an ordinary candle-flame by frosting the lamp and by the nature of the shade, then no harm is caused by the lights being visible.

It may be taken as established, therefore, that pendants are permissible, and the question now arises from whence they shall be suspended. Many circumstances will affect this question, of which the chief is the relative width of nave and side aisles. If the latter are absent there is a good deal to be said for the use of a central row of electroliers, comparatively large, few in number, and hung high. The position of the lights is excellent, the small number of outlets conduces to economy, and the opportunity is presented for the use of elaborate chandeliers, containing as many as 20 or more lamps. If side aisles are present, central fittings might still be employed, augmented by smaller pendants in the aisles themselves.

Central fittings, however, are a somewhat risky expedient æsthetically, as they are very likely to attract attention from the roof, often a beautiful feature of the building in itself: It is safer and much more usual to adopt a double row of pendants, corresponding in number to the pillars bays, or roof trusses. These would be more numerous and less prominent, and by their non-central position would not clash with the roof. If the side aisles are at all extensive, additional lighting will again be required there. There will in general be no difficulty as to the location of central fittings, for there are always points in the roof from which the suspensions can spring, such as bosses, rosettes, the middle of a roof truss, or the like; but the location in the case of the double row is not so simple. Occasionally the architect helps by providing what are called "hammer-beam" trusses, in which each roof truss first springs from the wall as a short horizontal cantilever on either side, and a semi-circular or pointed arch is based on the ends of these. An ornamental drop at the end of the cantilever forms a natural starting-point for the stem or flexible wire of a pendant, and as far as distribution is concerned the position is usually a good one. Its great objection is that the pillar, which ascends immediately below the truss, shades much of the light from the side aisles, and this effect is the greater, the higher the fitting is hung above the level of the capital. On the other hand, the surface of the stone, generally of a whitish tint, acts as a reflector for this intercepted light, improving the illumination of the nave.

If the lighting of the aisles by the same pendants be an important consideration, a position half-way between the pillars is advisable. In some churches the point of suspension is located at the apex of the arch, a practice not to be commended, as the line of the stem interferes with the lines of the structure. A much better method is to affix ornamental iron brackets to the wall vertically above this point, if the conduit can be sufficiently concealed by a convenient string course or moulding. Otherwise, stems may extend right up to the roof, and although the length of wiring may be longer than in the previous case, the greater ease of installing it above the inner roof may render this alternative the cheaper one. The appearance of the long vertical stems, in addition, is in keeping with the general character of Gothic design.

In some buildings, again, the fittings are hung behind the arch, and are thus outside the central nave altogether. They are well out of the line of vision, and are for this reason well placed; but from consideration of appearance the position is weak, being unsymmetrical and making the stems appear to issue from nowhere in particular. The pendants in the side aisles will occasion little difficulty.

With regard to the ornamental design of the electroliers, there is not so much restriction as many people seem to think. There is no more reason for a stereotyped pattern of light-fitting than there is in the case of the other church metal-work. The observance of two golden rules will be sufficient. One of these is to give due weight to the quiet dignity that should characterize everything connected with a church. Showy and theatrical effects must be carefully avoided, and especially imitations. The colour of the metal may with advantage be dull black, or oxidized copper, for it is a mistake to suppose that a polished brass finish is essential. The last named, however, is effective in an interior of red sandstone or similar material.

The second rule is a more general one, but applies with special force here. It is that ornament without utility is an abomination. An infraction of this rule mars one of our prominent Colonial cathedrals, where the light is derived from huge basket-shaped masses of bent ironwork, supporting (or supported by) four diminutive gas burners of about 40 candle-power each. In the chancel an exactly opposite policy has been adopted, which may serve to exemplify the other extreme. The principal choir desks on either side carry a row of plain uprights, each bearing at its summit, at about the level of the choristers' heads, two naked tungsten bulbs. Incidentally, this scheme provides a useful epitome of all the serious defects that a lighting scheme can ordinarily possess.

If the simplest possible fitting is decided upon, a prismatic reflector (such as an intensive Holophane) with an oxidized-copper gallery, may be used with a bowl-frosted tungsten lamp of about 200-watt rating, and the combination would be suitable and pleasing though merely supported by thick maroon-coloured flex. More ornament could be provided by using simple three-light electroliers, consisting of a stem and arms, from 12 in. to 16 in. wide, adorned only by simple scroll work. More arms can be fitted, but it is well to avoid four, unless stems are employed which keep the whole from rotating out of a position square with the building.

There are a few special positions that will require individual lights, of which the pulpit and lectern are alone likely to give trouble. In both cases it should be remembered that the reader or speaker himself needs to be illuminated; this and other conditions can be simply and effectively met by plain cord pendants from the roof. The opaque, or nearly opaque reflectors should be located a foot or two in advance of the

vertical line of the book-rests. Purely local lighting of the latter is neither easy nor satisfactory.

Intensity of Illumination.

There is only one consideration that requires noting in connection with the determination of the candle-power of the various lamps; otherwise the treatment of a church is the same as of other buildings. This is the great height of the roof. If the whole interior, high and low, is to be evenly illuminated, the candle-power required will vary more nearly with the volume enclosed than with the floor-space to be covered. Fortunately, this is not nearly the case; but the effect may be sufficient to upset ordinary calculations.

The actual intensity appropriate to the situation lies between 1·5 and 3 foot-candles, the choice depending to a considerable extent on the portion of the building under treatment. Special care must be taken in providing for the choir, who are in many cases reading nearly the whole time and require an amount in the neighbourhood of the upper limit given above. The congregation, on the other hand, use their books but little except when actually singing, and it will be found that a lower degree will as a rule be sufficient in the nave and transepts. In this connection, however, the decision of the minister and his committee should be obtained. It must be remembered that besides being wasteful, too great an intensity will also be objectionable to those present, many of whom will experience a feeling of drowsiness, a well-known result of too strong an illumination.

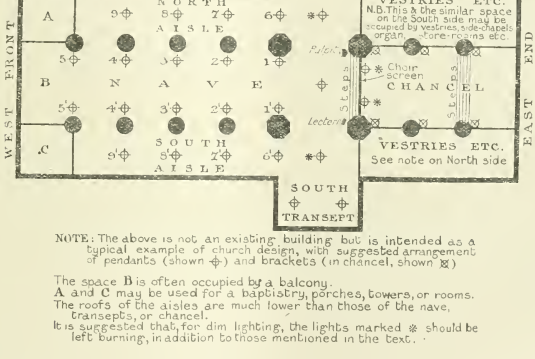
With regard to consumption, one candle-power for every 1½ to 2½ square feet of floor area will fulfil the conditions mentioned, under average circumstances. As is usual in lighting practice, these figures are influenced by the nature of the wall surfaces, and these are generally favourable to a high ratio of reflection. Brick and dark red sandstone are the least economical materials, and with the type of shades and fittings described, the darkest of these will require about double the candle-power that would be necessary for a building lined with limestone. If there is any doubt as to the requisite candle-power the installation should if possible be so designed as to permit after-adjustment by changing the lamps for others of slightly lower or higher candle-power.

Switching Arrangements.

There should not be any great difficulty in arranging for the convenient operation of the installation in spite of the large number of individual lights. The different combinations required are briefly as follows:—

(1) Complete lighting during service.
(2) Partial lighting before service.
(3) Partial lighting during portion of evening service.
(4) Partial lighting on dull days.
(5) Choir only (for choir practice).
(6) Parts of building only (for week-day services).

The above does not include the control of the vestries and other supplementary parts of the building, which are dealt with upon ordinary residence or office lines. These and any other likely combinations must be put into circuit with the least possible trouble and without attracting attention. The marching of a verger or other person to the rear as the preacher mounts the pulpit, followed by a series of aggressive clicks as



NOTE: The above is not an existing building but is intended as a typical example of church design, with suggested arrangement of pendants (shown ⊕) and brackets (in chancel, shown ⊠)

The space B is often occupied by a balcony.
A and C may be used for a baptistry, porches, towers, or rooms.
The roofs of the aisles are much lower than those of the nave, transepts, or chancel.
It is suggested that, for dim lighting, the lights marked ✻ should be left burning, in addition to those mentioned in the text.

circuit after circuit is put visibly out of action, should not be tolerated, and is not necessary on any grounds. It may cause serious annoyance to a visiting preacher who is not expecting anything of the kind, and if he be of a nervous temperament it may be sufficient to put him off his discourse.

The proportion of the lamps dispensed with at any juncture must be decided for each particular case, assisted by a knowledge of the local wishes in the matter. In general, about two-thirds of the candle-power may safely be shut down either when the congregation are assembling or during the sermon. Take for example such a case as that shown in the diagram on page 197. Here there are two rows of fittings in the nave, and one in each of the aisles, the latter of about half the candle-power of the former. In this case every other unit in the nave might be extinguished, as well as all those in the aisles. To facilitate this, alternate lamps would be wired together to form the branch circuits. For instance electroliers 2 and 4 would be controlled by the same switch and protected by the same fuses; this would also apply to 3 and 5, and similarly on the other side. The front electroliers (No. 1 and its fellow) would have switches to themselves, being most frequently required alone, while in the aisles the grouping would be 6 and 8, 7 and 9, and so on. Then either 1, 1′, 3, 3′, 5, 5′ could be left on; or 1, 2′, 3, 4′, 5.

The lights which are thus put out of action should all be controlled by a special switch, or pair of linked switches, in the choir, where a chorister can give the necessary attention without leaving his place.

Wiring.

It need hardly be said that the wiring of a church should be of the very best description, not only on account of the necessity of reliability and long life, but also for reasons of safety. A building constructed so largely of stone would not at first sight seem subject to risk of conflagration, but when the past history of our older churches is examined, there is scarcely one that is not recorded as having been burnt at least once, and there are many, like York Minster, that have suffered oftener. Thus heavy-gauge welded steel conduit only should be permitted, united by screwed joints. Sharp bends should be forbidden, and all joints should be of the inspection type. Under these conditions the cables can be easily drawn into place without any straining, unless the diameter of the conduit is stinted. Every care should be taken to see that the latter false economy is not indulged in.

With such long runs of conduit as will be found necessary, the question of providing sufficient earth connections becomes important. A simple test that may be imposed is the ringing of an ordinary trembler bell by means of two dry cells between the earth and any point in the system.

It is not always possible to conceal all the wiring, but by careful designing the conduit actually exposed may usually be reduced to such an extent as to escape the notice of an ordinary observer unless his attention be drawn to it. With the distribution board situated in the eastern part, the risers for the whole building can ascend to above the roof behind a chancel pillar, where they are quite invisible. When there is no option but to run tubing over the surface, it can often be led up the fluting or moulding of a pillar or wall, where it is not unsightly, if appropriately tinted and neatly executed.

If there is a gas installation, the run of the pipes will form a guide, and orifices through walls made for them may be found very welcome by the electrician. The much smaller size of the electric risers, however, will frequently make more direct routes possible. On the other hand, gas-fitters sometimes avoid piercing walls by taking their pipes out into the open air through the roof, and in again under the eaves, a practice the electrician would scarcely imitate.

Conclusion.

It is the author's hope that the above consideration will be of assistance towards the better carrying out of a far from simple task. Although the buildings under treatment are the most exquisitely designed and the most richly prized of any, yet it is noticeable that their lighting schemes are in only too many cases poor and unscientific. The fact that electricity is becoming more and more commonly used for the purpose emphasizes the desirability of improvement, for with it new and better methods are rendered possible. Yet in many of these beautiful edifices the work of the electricians provides the only unsatisfying feature. For some reason this branch has been left strangely alone by engineers, perhaps through apprehension as to its architectural associations. If any part of this paper will have helped in the direction of a fuller understanding of the subject, the avoidance of its pitfalls, and the grasping of its opportunities, the author will feel abundantly rewarded.

DISCUSSION ON "ELECTRICAL SIGNALLING AND CONTROL ON RAILWAYS." *

Discussion before The Institution, 10 January, 1918.

Mr. C. M. Jacobs (*communicated reply*) :

Signal aspects.—I do not see how the difficulty Mr. Hurst suggests could arise with a properly designed semaphore. As regards the "daylight" lamp signals mentioned by Mr. Thorrowgood, if these should prove effective a revolution in signalling practice will result. Answering Mr. Baker, the three-position signal aspect has nothing to do with the question of "normal danger" or "normal clear." Moreover, nearly all our signals are located at places where there are junctions or sidings. It is safer not to put such signals in the "proceed" position until a train is coming, than it would be to have them normally in that position and put them, as would often happen, at "stop" in the face of an on-coming train.

Indication of points and signals.—With regard to Mr. Hurst's point, what I had in mind was the desirability of not being able to give a train permission to leave A for B unless at the time B's signal was at danger. Accidents have arisen which this precaution would have prevented. In reply to Mr. Thorrowgood, common wires from the functions to the power supply, or power mains, is what it is suggested should be avoided.

Track circuit.—The graphs on page 137 were suggested by the perusal of the chapter on "Shunts" in the late Professor Ayrton's "Practical Electricity," and were obtained from his formula for ascertaining the values of the shunts for reducing the current through a galvanometer. This formula as applied to a track circuit is as follows :—

$$\frac{s\,E}{(s+g)\times r+s\,g}=\frac{1}{n}\cdot\frac{E}{r+g}$$

where S is the shunt, G the relay, R the battery series, and $1/n$ the required fraction of the unshunted relay current. It is much to be desired, as Colonel Pringle has pointed out, that some common basis for the installation of track circuits should be agreed to. The way I regard the matter is that the track circuit is there to take care of certain train shunts, which train shunts are comparatively high owing to the conditions obtaining in this country. To get a satisfactory factor of safety these train shunts must be ascertained, and to them must be subordinated all other track factors. The standard track circuit should be based on minimum insulation, not on length. Variables then would not have to be considered. Minimum insulation resistance occurs in a soaking rain and may be 10 times higher during a hard dry frost. As regards the shunting effect, 10 times the minimum insulation resistance is approaching infinity. It is better, therefore, to regard the maximum train shunt as acting at infinite insulation and not assume that the train shunt will be assisted by a ballast shunt, the latter being too variable. The standards I have suggested in some cases may be costly to attain, as shown by Mr. Downes, but it is a fact, nevertheless, that the higher the train shunt we have to take care of, the higher must be all the other factors. Mr. Thorrowgood's table shows this, although he has, unconsciously I am sure, made an unfair comparison between the 240-ohm and 4·5-ohm relays. He is, of course, wrong in saying that a 240-ohm relay requires less power than a 4·5-ohm relay. It is likely to be the reverse. He does not compare like with like. He has assumed either a different mechanical construction or a greater electromagnetic efficiency for the lower resistance relay than for the higher resistance relay. Moreover, he gets a much higher comparative shunt value than he should do for the low resistance relay, because for that relay he has assumed a "drop-away" current value as high as $83\frac{1}{3}$ per cent of the "pick-up" current, the same factor in the case of the 240-ohm relay being taken at 60 per cent. Calculating for 60 per cent to make a proper comparison, Mr. Thorrowgood's 11·25 maximum shunt becomes 3·3.

The three bottom rungs required by Mr. Proud are as follows :—

(1) The minimum insulation should be a little less than double the fixed train shunt.

(2) The relation of the series resistance to the relay resistance is, as regards shunting, immaterial. It depends upon the power available.

(3) The ratio between the current in the relay at minimum and infinite insulation is to be obtained from the graphs in Fig. 4. For example, take the curve S = R. Let minimum insulation equal 0·5 relay, then the current through the relay is one-half the current which would pass through the relay at infinite insulation, i.e. when there is no shunt across the relay.

From what I have already said, Mr. Downes will see that I am in favour of scrapping variables.

With regard to Mr. Thorrowgood's point about single vehicles being left on class A tracks, all I can say is that it is not a class A track if it is one which may be acted upon by a single vehicle. If impedance bonds across the rails have not been considered, there should be no reason why just as good shunting should not occur with alternating as with direct current ; all that is required is a suitable relay, which need not necessarily be non-operative with direct current. I agree with Mr. Roger Smith that we should extend the use of alternating current for track-circuiting. In a large installation maintenance would be much less.

The American proposal to use a 2-ohm relay with

* Paper by Mr C. M. Jacobs (see page 130).

a 6-volt battery, referred to by Mr. Lascelles, means a very low shunt. American conditions are quite different from British. I believe that in America heavy vehicles with all-steel wheels are universal, so that they are more likely to get low shunts than we are. Then, again, American practice for train protection is different. When a train makes an unusual stop a trainman goes back to protect it. In this country, however, it is usual to rely on the track circuit alone for protecting a standing train. Hence our necessity for a high standard of shunting.

Mr. Gott's suggestion is hardly practicable. Moreover, a train shunt which would short-circuit a no-voltage release coil would equally short-circuit a track relay. The less the difference between the "pick up" and "release" current values the more sensitive is the relay to shunting.

Automatic train control.—Colonel Pringle considers that the missing or misreading of home and starting signals by drivers should be provided for. I think everyone will agree this should be done if it is practicable. There are difficulties, however. Mr. Insell has pointed out the difference between the conditions on main lines and tube railways. At the present time on main lines the home and starting signals mark points beyond which it is dangerous to pass. There is no overlap, and an overlap, if practicable, would have to be long enough to admit of the heaviest and fastest train being pulled up within a safe distance after over-running the signal. I assume it will be granted that such an overlap is out of the question. If so, the irrevocable application of the brakes must commence at a distance behind the home or starting signal equal to what the overlap should be. In many cases this would be as far out as the distant signal. Perhaps, however, Colonel Pringle is satisfied with the revocable brake application as being sufficient for running trains, and only advocates the irrevocable brake application to meet the case of trains starting against signals. If so I think it might be taken that a revocable brake application at the home or starting signal would be as effective as an irrevocable one. As a compromise it might be considered whether a time-release brake application should not be made whenever a distant home or starting signal is passed otherwise than in the "proceed" position.

As regards the objection to signalling to the cab of an engine, if any operation is effected in the cab of the engine from without it necessarily in the driver's mind partakes of the nature of signalling to him. I think, moreover, it may be taken as a fact that no system which communicates in any way with the driver will be considered of any use to him unless it gives him a positive "proceed" indication. That is the conclusion I have come to as the result of some years experience. During the recent foggy weather I have heard of a difficulty in getting a driver to take out his engine because his automatic train-control apparatus was not working; and the fact that this appliance would give him "proceed" indications was, I believe, in his mind. There is a good deal of psychology in the problem of automatic train control, and it would seem very desirable to know just what drivers themselves really want.

Answering Mr. Roger Smith, what I had in mind was that direct-current electrification would necessitate a fourth conductor rail. As apparently it does not, there is nothing in my point. If direct current is used for traction on main lines, alternating current will apparently be necessary for automatic train control as well as for track-circuiting. So far we have not tried alternating current for automatic train control.

Single-line working.—With regard to Mr. Lascelles's remarks, as a rule single lines are provided because the traffic does not warrant the cost of a double line. The trains mostly stop at all stations and there is plenty of time to exchange tokens. A token system in practice is as safe as any other system, and moreover it is economical. The most important single-line tunnels on the Great Western Railway are worked by lock and block, and no doubt there are cases where it would be an advantage to control single-line working by track-circuiting as Mr. Lascelles suggests.

I note that Mr. Baker finds the paper somewhat scrappy, but, as he says, signalling is not very homogeneous, nor do I see very well how it can be otherwise, considering the variety of conditions which have to be provided for and which necessitate the use of practically every known electrical device.

I agree with Mr. Lascelles that linemen should be encouraged to become efficient in electrical matters. It is not satisfactory to be introducing new and often complex systems without paying attention to the education of the men who have to look after them.

I am glad to find Mr. Roberts in agreement with me about the human element. I feel sure the best results are only to be obtained on main-line railways with their varying conditions and constant emergencies if they are intelligently staffed and the staff supplied with efficient appliances.

Manchester Local Section, 15 January, 1918.

Mr. J. Sayers: I do not propose to discuss the paper in detail, but just to take two views of it. Possibly some of those present do not know what is centred in an ordinary main-line signal box. If we went inside we should find a very large number of instruments, all of which are worked electrically; that is to say, they are operated by electric current, or they are brought into operation by the absence of current, and very often they are controlled from distant points of the line. We should see quite a large number of instruments which tell the signalman exactly the state of the lines under his control; the position of the signals controlling the lines; whether the lamps are lit; whether the traffic is occupying a position where he cannot see it; whether facing points have gone over properly; whether switches have gone over properly and are in their correct position; and at a junction, for instance, whether the last vehicle of a train has

actually cleared the fouling point to permit of a train crossing behind it. In some cases we should also have several track circuits, with their indicators and locks; also, probably at least two telephone circuits and perhaps a telegraph circuit. The net result is that each signal box, on the main line at least, is really a little power centre or station, which requires a supply of electrical energy on quite a large scale as regards the number of circuits. These are of the nature of standard requirements, but there are always others. More and more we are asked to take out of the hands of the signalmen responsibilities which are proving too much for them, and to do something automatically instead of letting it be done by hand and eyes. We have got to a point at which what we can do is really limited by one thing, namely, the supply of electrical energy. It is certain that, on the Midland Railway alone, in connection with signal-box circuits there are roughly 150,000 primary batteries. They are not altogether the easiest things to maintain, and unfortunately they have to be maintained in very bad positions such as at "distant" signals. We are being pressed to do more in the way of automatic signals. Automatic signals of the usual type—the arm type—require quite a considerable expenditure of force to make certain that they will operate in all weathers; and as we do not like signals to come off very slowly, one has to provide a battery which will supply a very considerable ampere output with a low internal resistance. As a matter of fact the number of primary batteries which will operate such signals is very limited indeed. I can say that unless we can put in a continuous power main the problem of supplying automatic signals is very difficult; in country districts we have got to use a soda cell, or something of that kind. I have been experimenting for two years on the best type of primary cell, and I find that a unit of energy from an ordinary Leclanché cell cost about 50 shillings in pre-war times; it is probably now cheap at £3. On the point of economy alone it is desirable that we should be able to get electric power for doing these things from a central station. I think I have indicated the point I want to make: it is that in my opinion the development of proper control of signalling is in the direction of making it more automatic; and this development is going to be stopped unless we can get a proper supply of energy along the railway. We must have two things: in the first place we must have a supply which is not too costly; and secondly it must be absolutely reliable. When I was over in America with my colleagues, one of the things which we saw was a system of feeding the signalling arrangements on the railway between New York and Chicago. There they have a continuous system of controlling automatic signals, some of which are of the arm type but are all automatic. They do it quite well and cheaply, and without any trouble, by having a continuous overhead power line along the whole line, and they feed into that any sort of supply they can get. They have their own power station, but by the method of bringing in everything all along the line they ensure that if there is a failure of supply at one place they can get a supply from the other direction. Even if their own line is out it is only the signals in the vicinity which are thrown out. This is the sort of thing I think we have to get in this country, if we are to develop signalling properly. The other point I should like to comment upon is the question of train control. The author says: "A non-contact method would have been preferred, but so far no such scheme has been considered practicable"; that, of course, is his personal opinion. There are some who think that an inductive method is likely to be practicable. Only those who work on the railway know the trouble there is with obstruction, and in no place is obstruction worse than between the running rails. The division between the rolling and structure gauges between the rails is very small. For electric traction purposes these of course have to be made to meet, but I well remember the trouble I had to go through on this point (the meeting of the rolling and structure gauges) when designing the overhead equipment for the Heysham, Morecambe, and Lancaster single-phase electrification. So we have to compromise; but there is a very great objection indeed to having anything on the track. Any ramp method of control is non-continuous; we get communication only at certain points. The Great Western system is one of the ramp methods, and in my opinion is the best of them all. We have had it in use on one of our lines for something like 10 years, and it does exactly what it was put in to do. I need hardly explain that the great point is to get communication between the stationary track and the moving train; if we can get that we can do what we like with it. With a ramp, the communication is not continuous; it is obvious, therefore, that the thing is in action only when we are passing over the ramp. If the ramp disappears from any cause, the control disappears; or if the shoe disappears the control is likely to disappear, though this may perhaps be provided against. On the North-Eastern Railway, I remember at one time if we walked through on the line we could find fair evidence of the loss of engine shoes; then the system, of course, is not operating at all. Methods could be adopted to inform the driver that it is not operating, but I think most people will agree that is a development which should be avoided if possible. If we have an inductive method, it is essential to have a conductor along the whole length of the line (preferably buried in the ground) and supplied with alternating current at a predetermined frequency. We therefore have a sort of continuous pulsating magnetic field, and when we want that field to disappear (at the places, for instance, where the signals are at "danger") we so arrange the conductors that for a certain length of the line the magnetic field is practically zero. We have got a relay which will operate with alternating current of a certain frequency within limits, by using the tuned reed relay of Kramer and Kapp, the only one I know which will work; it will operate continuously and make a contact with a frequency of 100, breaking at above 105 or below 95. With a system of this kind, with such a relay, we can do anything we like. We have continuous control of the train from the time it starts to the time it stops. If any-

thing happens to the circuit on the engine or in the ground, the control current stops, the relay stops, and breaks the main control contact on the engine. One of the limitations of such a system at present is the necessity for power which has to work 24 hours a day, 7 days a week; and although we have got the current in the ground circuit and the necessary control mechanism down to a low figure, still it means very considerable expenditure of energy, and probably a special alternator to supply the energy within the wide limits of the usual supply pressure. Such a system undoubtedly will depend upon having a continuous supply of power all along the line, so that it seems that both the old forms of control that we have now and those which will probably be used in the future on the railway depend upon a proper supply of power. Requests for electric light signals for a considerable number of places have been put into my hands for consideration, and it is a most difficult job. We can do it by secondary cells, and changing them, but that is a very inconvenient way. If we had a supply of power all along the line, the requests would no sooner arrive than we could put the thing in hand. I should like to reply to the remark by Alderman Walker (see below) about the opposition of railway companies to the transmission of power near their lines. So far as I know, the only opposition results from the difficulty of preventing induction on the telephone circuits; that is the sole reason. The Midland Railway maintain important trunk circuits as well as their own, and we cannot possibly allow anything to interfere with their operation. The margin for commercial working is very small; a very small amount of want of balance on the circuit makes it unworkable, and for this reason we have to be very careful, so far as we have power, to keep these lines free from induction. On the other hand, I can say this: that I myself had to do power work, and I was largely responsible for the design of the electrification for the first single-phase railway in the British Empire, between Heysham, Morecambe, and Lancaster. We found the difficulties due to induction from the overhead line to the telegraph and telephone wires to be very great indeed, and very nearly insoluble. We worked with the Post Office engineers in endeavouring to find a solution, though I am bound to say that no practical solution has yet been found. We have done everything we can to help other people, but I have found that they are unable apparently to take advantage of it. At the present moment I have several power crossings before me; one is in the Midlands where it would have to cross a four-track line. From the point of view of the power engineer I have tried to make that crossing an open crossing, but in this case those responsible seem to be unwilling to allow me to take the burden on our road. We have, of course, to consider the interest of the railway, even from a physical contact point of view, and the crossing of the main line of a railway is rather a portentous thing to look at; it is all right in the summer-time, but in the winter, with a gale of wind and snow, one does not feel so happy about it. As regards a power line paralleling a railway, if one can get a company to put up a three-phase line and guarantee that the phases will be equally balanced, and that if necessary they will cross the power lines and transpose them, I do not think it will be found that any railway company will put difficulties in the way. With, however, a single-phase line, or a three-phase line which has lighting on one phase and something else on another and has its phases therefore unbalanced, we have to consider that that will almost certainly cause trouble with the telephone lines. Theoretically a telephone line is balanced against a magnetic field by being revolved, but in practice one cannot get the wires symmetrical; the insulation of the two wires also can never remain equal, and a telephone circuit with an insulation of, say, 1,000,000 ohms on one wire and 500,000 ohms on the other will not be workable alongside a single-phase line.

Mr. P. Lomas: In reading through the paper one point impressed me rather forcibly. That was the pessimistic view the author seems to take of his profession. On the first page he says: "Mechanically-operated signals are particularly liable to give such false indications, and the best-designed electrically-operated signal is not free from the defect." A few lines later he points out that the electric repeater of a signal is not altogether reliable. Still, a gleam of hope appears on page 137 where he says: "These safeguards can only be made thoroughly effective by working the signals, and detecting the points, electrically." He gives the real reason for his pessimism on the last page where he says: "There is, however, sometimes a tendency to expect what almost amounts to infallibility, an idea which has probably been fostered by somewhat enthusiastic advocates of electric systems who talked about the elimination of the human element." I have been actively concerned with a number of electrical appliances on one of our large railways for some time, and I am sorry to see this pessimism, especially on the part of the author, who is a contemporary on the same class of work as myself. I have in mind something like 300 sections of track circuit and I must say that the failures on the relays connected with these work out at considerably less than one failure in a million operations. That is hardly just cause for pessimism. It is only fair to electric signal engineers as a body that it should be realized that although failures do occur they are not nearly so frequent as they would be with mechanically-operated devices, but, as the author states, owing to the fact that it is more difficult to describe a failure when it is electrical, people seem to be afraid and think that because a piece of apparatus has failed once it will fail again. The better view to take of it is that if it is safer than mechanical working, no matter how often it fails, it should be adopted; but when we get failure so rarely as once in a million operations (or considerably less in some cases) I think it can safely be said that the electrical signalling apparatus on railways is very successful. On page 137 the author says: "A track circuit cannot be depended upon to detect anything which does not put virtually a dead short-circuit across the rails." In practice the term "short-circuit" is a comparative one. To one man a contact having a resistance of a few

ohms is a short-circuit, whilst to another man the same few ohms may be the value of the insulation resistance, and he does not regard even 0·1 ohm as a dead short-circuit. Exactly what is meant in this case it would be interesting to know. I may say that on the London and North-Western Railway no track circuit is allowed to remain in use if it will not operate with 1 ohm joined across the rails, and having once operated it will not restore itself until the value of the short-circuit caused by the train wheels rises to about 5 or 6 ohms. When dealing with railway track-circuits, bearing in mind the multiplicity of intricate controls of signals and block instruments, and considering that we are bound to employ timber sleepers and wet cinders for insulation instead of vulcanized rubber, we shall realize that we are up against a serious proposition; for instead of reckoning our insulation resistance in megohms we often have to reckon 2, 3, or 4 ohms as a fair insulation resistance. These are difficulties it is well to realize we have to contend with in railway work; and when we get failures so infrequently under these conditions, as I have mentioned, I think we shall agree we are doing fairly well.

Mr. G. Morris: There is no doubt that, in regard to the protection of trains, everything possible is being done to make the track circuit invulnerable. To condemn a thing because it fails once is to my mind not fair. From the large number of track circuits which exist at the present time there is every reason to hope that railway travelling will be the safest thing in locomotion.

Mr. J. D. Paton: It is to be regretted that those who have been in the United States did not pay any regard to the work which has been done there by the Simmen Company on the Pennsylvania Railway, on a main branch of the system. The control of the line and the acceleration of dispatch and traffic is the basis that has to be considered, and one of the first features to remember is the deletion of effort by the individual. No attempt should be made to establish a system by which the signals are not a part of the locomotive. In the Simmen-Northey system the signals on the ground are cut out. The only objection to the system by an eminent British signal engineer was that the human element was absent; he could not tell what was on the line and he could not see the track ahead. The signals are given in the engine cab. It is characteristic, I think, of the two countries that in this country we work first of all on the principle of making sure about the "danger" and then go ahead; in the States they work on the "all clear." Then again on this system not only is there a track circuit to the engine, but the idea of a recording system has also been introduced. I had the privilege of seeing in this country a very close approach in an attempt to establish a basis of operations by hand, what is already done automatically by the Simmen system. The man in the Simmen control house has a panel in front of him which represents the entire system of blocks of which he is in control. Every train on that system is moving on that panel and he actually sees a small needle perforating the position of the trains inside the blocks. In a Court of Law these records are now recognized as superior evidence to oral evidence in a case of accident. This system has reached a point where it has become a great success. What I plead for is not an individual operation where each man has a section or system of his own, but the vital question of efficient transport to be decided from the best of all; it is a matter for national investigation, and then action by this Institution.

Mr. W. A. Barnes: The author states on page 140: "The disposition of the shoe and ramp, viz. in the centre of the running rails, is the most practicable and convenient, and this, as safe signalling is an important factor in railway operation, may become a reason favouring the adoption of alternating current for railway electrification." It is difficult to find a reason for this, as no matter what system of electrification is used it is not necessary to occupy the centre of the running rails. Alternating-current traction has yet to prove its case in this country; heavy electric traction is almost wholly direct current, and the probabilities are that extensions will be on the same lines, especially where suburban traffic has to be dealt with. The system adopted for electrical signalling should be adapted to the kind of electric traction in use rather than as suggested by the author. On the Manchester-Bury electrified section of the Lancashire and Yorkshire Railway, track signalling with batteries was in use prior to the electrification, but, owing to the voltage drop in the track rails being very variable, and under certain and frequent conditions higher than the voltages used for the track circuits, it was necessary to change over to alternating current for the track circuits. There is an alternating-current lighting line running the whole length of the electrified sections used primarily for the lighting of stations, and power is taken from this through transformers for track circuits. This is very similar to the system which Mr. Sayers has told us exists in America, and the operation has been quite satisfactory. From the present condition of electric traction, therefore, and the possibilities of its future extension, it would seem essential that electrical signalling should be operated primarily by alternating current. This would at once solve the problem just mentioned by Mr. Sayers in connection with the high cost of providing and maintaining millions of primary batteries, and would reduce very considerably his figure of £4 per kilowatt-hour of battery output.

Mr. A. Davies: Mr. Sayers did not mention an arrangement which has been introduced on the Midland Railway, known as the rotary block instrument. This is an arrangement which combines the block telegraph circuit with the ontside signalling installation, and ensures that a signal shall not be lowered to permit a train to travel along the line other than that for which the necessary permission has been given. With regard to the statement at the foot of page 136, namely, that "in the case of block signalling it should not be possible to place a signal in the 'Proceed' position unless at the same time the signal in advance is at 'Stop,'" I should like to know whether the author considers it advisable under all conditions that such a principle should be adopted, because it seems to me that under certain circumstances such an arrangement would cause delay in dealing with the traffic. For instance, take a junction signal-box B. It is possible under present conditions for a train to be approaching from signal box A which requires to travel in the direction D, with the points

set towards the direction C because of a train travelling from C towards A, and when the train from C has passed over the junction points at B the signalman then reverses the junction points towards D and, having got permission previously from the signalman at D, lowers the signals; whereas if the arrangements suggested were in force it would appear necessary to hold up asking for permission until the train from C to A had actually passed through the junction.

Alderman W. Walker: I am strongly under the impression that, from the first, all schemes for the long-distance transmission of electrical energy have been opposed by the railway companies; they have not wanted transmission lines anywhere near their railways. In the discussion the electrical engineers of railways have complained because current is not available at every point on their systems where they now require it for some particular purpose. I rejoice therefore that at last their assistance may be expected in the development of high-tension transmission, overhead or otherwise, and that they will so influence the powers that be.

Mr. C. M. Jacobs (*in reply*): I am glad to find Mr. Sayers emphasizing the limitations imposed on electrical signalling development by the lack of a suitable power supply. Not only is the primary battery insufficient, but, as I have pointed out, it limits the efficiency of signalling apparatus. With regard to automatic train control, I agree with Mr. Sayers that it is desirable to keep the railway free from all unnecessary obstruction. I do not think, however, that those who believe in an inductive method of signalling to the train have yet shown us a practical scheme worked out in all its details. From a purely signalling point of view I do not think a continuous indication on the train is necessary. The present semaphore system of signalling gives intermittent indications, and these, if they are properly observed, are found to be sufficient.

Mr. Lomas has evidently noted an absence in the paper of complimentary reference. One idea of the paper was to show there was room for some improvement and incidentally to point out how improvement might be effected. For example, I have tried to show how the track circuit might take care of the single vehicle. That it cannot be relied upon to do this has always been considered to be a great drawback. When Mr. Lomas is up against the single-vehicle difficulty he apparently very simply disposes of it by eliminating the track circuit altogether. This is because he limits his track circuit to a 1-ohm train shunt. When, however, I am at some pains to show him how to take care of a very much higher train shunt, he exclaims that I am a pessimist.

I hope Mr. Morris will be happier with his track circuit when he realizes that the one failure which he seems to admit may perhaps be eliminated.

I have not had an opportunity of seeing the Simmen system referred to by Mr. Paton. With regard to his remarks that in this country our method of working is first to make sure about the "danger," whereas in the United States they work on the "all clear," I was under the impression that the watchword on the other side was "safety first."

Mr. Barnes raises a point similar to that raised by Mr. Roger Smith which I have already answered (see page 199).

Answering Mr. Davies, I think under all conditions it should not be possible to place the starting signal for "A" at "Proceed" unless at the time the signals for the same line at "B" are at "Stop." I do not see any risk of delay in the example mentioned by Mr. Davies. The only condition imposed on "B" in regard to accepting a train from "A" is that "B" signals for trains approaching from "A" shall be at "Stop" at the time the train is accepted. This would not prevent permission being given for a train to leave "A" for "B" when a train was approaching "B" from "D," as "B's" signals for trains from "A" would be at "Stop."

DISCUSSION ON

"ELECTRICAL COOKING AS APPLIED TO LARGE KITCHENS." *

Scottish Local Section, 8 January, 1918.

Mr. C. G. Nobbs : In the London discussion (page 103) I dealt with the running and maintenance costs of installations A and B. With regard to load factors, it is essential to give quick service. This entails comparatively high current ratings to ovens, boilers, etc. With well-constructed apparatus the running load is only 25 per cent of the full-load rating. In the case of ovens of the restaurant type, the full load may be on for 15 to 45 minutes to bring the ovens to working temperatures, while the running load may be on for hours according to the weight of the joints. There is, however, a large diversity factor which tends to increase the load factor. From the great similarity of the load curves given in the paper, one might think that these had been selected. Experience of cooking schemes shows that the diversity factor is large, as menus vary from day to day for individual installations and there is also a wide variation in the class of restaurant and the daily menu. Until such time as the supply authority can take on all classes of consumers, it is quite feasible to select or arrange with consumers to give a high resultant load factor and flatten out the curves of diversity. For example, a communal kitchen will complete its cooking, say, between 7.30 a.m. and 10.30 a.m. A scheme with which I had to deal recently will cater for 40,000 to 50,000 meals daily, and it is quite feasible in this case so to arrange the menu that roasting and baking work may be done at any time the day before upon a restricted-hour basis. A combined electrical and steam plant for an individual communal kitchen could easily be arranged to give a load factor of 50 to 70 per cent. Apart from this it will be seen that the deep valley in the author's curves between 7 p.m. and 10 a.m. can be filled in. It would be very instructive to have a continuous record of installations A and B to show the demand factor for a period of a fortnight and its relation if possible to the number of meals and the weight of food cooked. For individual installations working under normal conditions the maximum demand seldom exceeds 50 per cent of the total current-rating. In fact, for some jobs with which I have been connected, the transformers installed are but 50 per cent of the total rating in watts of the cooking plant. It would have been interesting if the author had given particulars of the output in cooked and baked food of individual pieces of apparatus in relation to their current consumption. An oven which I designed in 1912 for a 50 per cent load factor for baking 500 loaves per hour gave a temperature rise from 50° to 425° F. in one hour, and to 600° F. in two hours, and maintained a gradually rising temperature from 425° F. at half-load. The consumption varied from 1/10th to 1/12th of a unit per loaf according to the class of bread baked. The desirability of the standardization of electric heating elements was mentioned in the London discussion. I quite agree, but it is not advisable to carry standardization too far at this present comparatively early stage in electrical cooking, as progress in design may thereby be handicapped. There is no reason why contractors should not stock manufacturers' standardized elements or renewal parts locally in order to save the delay in transit from the makers. Experienced care is necessary for the fitting of renewal elements, and such work should be done by local contractors or hiring authorities. It will be understood that even were elements made as simple to renew as the ordinary glow lamp, it is very doubtful whether the average cook would be induced to put her head into the oven, much less attend to screws and nuts or investigate a breakdown. Where an establishment such as an hotel, restaurant, or institution employs a resident engineer, he will carry a requisite stock of renewal elements. Co-operation between supply authorities, factors, contractors, and manufacturers is most essential for the propagation or organization of national sales' campaigns, for the collection of technical data, education of the public, etc. It is necessary that each supply or hiring authority apart from advisory committees should employ a competent man or men accustomed to meeting caterers, chefs, architects, and the like. Purely electrical men seldom make efficient salesmen. Personally I prefer to train men having had experience in coal, gas, and steam-cooking upon the simple electrical data necessary. There is ample scope for consultants in cooking to advise caterers, architects, supply authorities, contractors, etc., upon large schemes.

Mr. R. Hardie : Our first experience of electrical cooking on a large scale in Glasgow was an installation in a club restaurant about seven years ago. We are only now beginning to live down the bad effects of this pioneer installation, on account of the primitive nature of the apparatus then available and its unsatisfactory behaviour. We are, however, about to convert a kitchen in one of the principal Glasgow restaurants and this will doubtless give a fillip to business. I shall be glad if the author will indicate the rate charged for current supplied to installation A, as the rate of charge seems to me to be the determining factor. With regard to staff cooking, we equipped the first all-electric canteen in Scotland fully a year ago. This was of 56-kw. capacity and was designed for catering for 250 workers. It has been an unqualified success. At the moment we are completing three all-electric installations, one of 45 kw. for 100 people, one of 70 kw. for 250 people, and one of 137 kw. for 500 people. We have in addition an 80-kw. electrical cooking

* Paper by Mr. W. A. Gillott (see pages 92 and 153).

equipment at a large hospital. The apparatus has been in use for two years and the average daily consumption is 130 units, or 0·37 of a unit per person per day. The boiling and steaming are done by steam. In a Government factory in the West of Scotland there is an electrical equipment in four kitchens, aggregating 350 kw. It has not been possible to obtain figures regarding consumption, but the plant has been running satisfactorily for over a year. Here again the boiling and steaming are done by steam. Personally I am an optimist on the subject of electric cooking, and I agree with the author that the field for electric cooking—and I might add industrial heating, which is after all a similar problem—has so far been only scratched; and if the business is properly handled, electricity-supply authorities have in electric cooking and heating a source of revenue second only to that derived from power. For example, we have just converted a coke-fired baker's oven to electric heating by means of six 3-kw. heaters fitted to the roof of the oven. If the running cost does not prove excessive, there are five other ovens awaiting conversion. The total maximum demand is 108 kilowatts. At present the factory is electrically lighted and a 5-h.p. motor is in use, the total demand being about 10 kilowatts. I am in agreement with the author on the substitution of self-contained element apparatus for boiling-rings, which still continue to be the weak spot in electrical equipment. Makers have not yet provided us with a satisfactory substitute for the gas boiling-range, and it would be interesting to learn from the manufacturers what hopes they can hold out for improvement in this direction, as we have made no progress for a number of years. Personally I would not think of letting domestic electric cookers on hire until we get over this difficulty. One has sufficient worry in maintaining in commission apparatus that is satisfactory—at least when it leaves our hands—but I, for one, cannot become enthusiastic about apparatus the deficiencies of which are patent before it leaves the works. It was a humiliating experience when in London recently to visit a restaurant kitchen where the apparatus was all electric except the gas boiling-rings over the oven, and I was informed by a supply company's engineer that he was obliged to get gas rings fitted on electric cookers in place of electric so-called boiling-rings. To my mind gas is the competitor calling for most attention; and from conviction, with the exception already mentioned, I claim that what gas can do we can do better, and there is no reason why our running costs should prove prohibitive.

Mr. W. B. Smith : I think the author has given us a great deal of information, invaluable not only to those who have large electric kitchens connected to their mains, but also to those who have not yet got past the domestic cooking stage. In Greenock we have given favourable terms for cooking for almost nine years, the rate being $\frac{3}{4}$d. per unit, which has only recently been increased by 5 per cent. We have, however, been seriously handicapped by our early attempts with certain classes of cooking apparatus, which eventually had to be taken out and scrapped. Only in a few of these cases have the old appliances been replaced by something more reliable. There are no large kitchens in Greenock fitted entirely with electric cooking apparatus, but we have a few partly-electrical kitchen installations in shipyards. These have only been fairly satisfactory, the principal defect with the cookers being in the hot-plate. I think the manufacturers might do something to improve the electric hot-plate, and I would suggest that, instead of adopting the flat-surface cast-iron hot-plate, they might experiment further with radiant-heat plates with easily renewable elements—elements that could be quickly replaced by inexperienced persons. In Scotland there is a greater demand for stews and fried foods than in England, and the hot-plate is therefore all the more important. The electric grill and electric baking plate are the most popular pieces of electric cooking apparatus in our district. We have a number of these appliances in restaurants and bakeries, and they have given great satisfaction. In the design of the cooker, which the author has referred to, I think it is a very good plan to have fuses on every element, and that point cannot be too much emphasized. In Greenock we have had experience of the whole cooking outfit becoming disconnected through earth leakage on one of the elements. With regard to earthing the frame of cookers, there are, without doubt, many cooking appliances in which the insulation of the elements will not withstand a pressure of 250 volts continuously to earth. I have had on many occasions to disconnect the earth wire from cookers in order to avoid interruption to cooking operations. Regarding the connection of cookers to circuits at pressures above 250 volts, I have in larger installations advised two separate cookers, placed some distance apart, connected one on each side of a three-wire system. The series-parallel arrangement of cooking elements is a good one, not only from the point of view of the life of the element, but also on account of the even distribution of heat on "low" heat. From $5\frac{1}{2}$ years' personal experience with various types of cookers in my own house, I have come to the conclusion that the oven with top and bottom heats is superior to the oven with side elements, provided that the bottom element is protected so that grease cannot be spilt on it. The advantage I find is that, after the ordinary operation, "browning" can be done by putting on the top heat only. In regard to the first cost of electric cooking installations, I do not think this should much affect the question of installing large cookers, as I believe most municipalities at least are willing to assist restaurateurs or hotel keepers in the installation of these by offering suitable hire terms to include the maintenance of the cookers. We have had a hiring scheme for heaters and cookers for over 10 years and full advantage has been taken of it by our consumers. In summing up the benefits and economies of electric cooking as compared with gas, steam, and coal, the author does not mention the cost of labour in preparation of materials and apparatus, inseparable from coal and steam, which must be considerable.

Mr. S. B. Henderson : I am considerably interested in the question of cooking by electricity. From the point of view of biscuit manufacture it presents some new problems. The convenience of electricity

for baking is, I consider, very great. There have been developments recently in connection with gas-firing for bakers' ovens. The efficiency of the old coal-fired oven was very low, and while the gas oven is much better than one using coal there is still considerable waste heat in the flue gases necessarily drawn off, and this waste is entirely obviated with electric heating. We found, however, that electric heating raised the problem of steam. Steam in the oven may or may not be desirable. In biscuit-baking we want steam at the first part of the operation, but a dry atmosphere towards the end of the operation. By getting the elements as close to their work as possible we reduced the area of the baking chamber to as small dimensions as we thought convenient. We then found that the steam produced from the goods entirely saturated the atmosphere in the baking chamber. The removal of that excess steam indicates a possible source of heat loss comparable with the flue-gas loss. It would be desirable to have some arrangement for abstracting the steam in the form of water at atmospheric pressure and using the incoming cool air to condense the water. That is one of the problems which arise in applying electric heating to biscuit-baking.

Mr. A. Mears: I am very much interested in the load curves in the paper, as the shape of these curves is an important matter when it is remembered that heating units must be supplied at a cheap rate. I notice that for the four restaurants mentioned in the paper, the annual consumption can be taken as 285,470 units, and the maximum rating is 452 kilowatts. The load curves are given in amperes and the rating in kilowatts, but the total maximum demand appears to be about 160 kw., or the equivalent of about 5 hours' use per day of the maximum demand, which is quite good. I think the matter might be looked at from another standpoint, namely, what is the load factor on the basis of the maximum demand during peak-load hours? From the curves before us, it is evident that the maximum demand during peak-load hours is only about one-half of the maximum demand at noon, consequently the load factor can be considered to be doubled. Naturally, if this view is taken when considering the cost of supplying such a consumer, the diversity factor must be taken as unity. The load curves are for restaurants, but it appears to me that with a large hotel there would be a higher proportionate maximum demand between, say, 4 p.m. and 6 p.m. than in the cases quoted, and thus the load factor would be reduced. In Edinburgh, as there is no hiring-out scheme, consumers must purchase their own apparatus. Consequently, electric cooking for ordinary domestic houses has not made much progress.

Mr. A. R. Wood: The amount of interest shown in this subject, particularly by some who are not members of the Institution, is considerable, and the figures we have before us, obtained from the numerous kitchens now in operation, should go a long way towards dispelling the doubt and suspicion which, in certain quarters, has held considerable sway. The question of design has not been given much consideration in the paper. One has only to inspect a few existing kitchens in which steam, coal, and gas appliances have been installed, to appreciate the fact that considerable improvement can be made in standardizing various parts, and that, if manufacturers of electric cooking apparatus follow on the old lines, the result will not be what might be desired. Before it is too late, is it not possible to arrange some standards, both as regards structural design and lay-out of heating elements? This, I think, can readily be done without unduly tying the hands of the inventor and the manufacturer. In the London discussion, Mr. Fletcher (page 105) raised the question of the uniformity of dimensions of elements, but there is no reason why this standardization should be limited to elements alone. In fact, the present time can almost be called the "age of standardization," and the opportunity for embodying certain standards, and also the metric system of dimensions and weights, is too good to be missed. We have only to observe the achievements of some of our Standardization Committees to see what can be done in this direction if the matter is properly tackled. I am somewhat surprised that no mention has been made of the application of electricity to ships' galleys. In view of the future development of the shipbuilding industry, the conservation of our coal supplies, and the utilization of oil fuel, the question of complete electric or combined steam and electric galley equipments is now brought prominently to our notice. The appliances would, of course, differ considerably in design in many respects from those used in ordinary kitchens and canteens, but this would not prevent the same good results being obtained. I understand that certain shipping companies are at present giving this matter their careful consideration, and tests are being made and recorded. In view of the unique position of the Clyde in the shipbuilding world, it is to be hoped that members of this Local Section will not be found wanting in giving every assistance to the development of electricity as applied to ships' galleys. It is not a question of the galley only, but the supply and housing of the necessary generating plant to carry out the work in the galleys.

Mr. W. A. Gillott (*in reply*): In reply to Mr. Nobbs, the load curves were taken from a record of one week's duration, and are in each case the second and third days' performance; the characteristic of each day is, however, similar. I agree that in very large kitchens where 50,000 meals are catered for daily, considerable work can be performed at off-peak periods by the night shift. In setting out a scheme for a large kitchen I estimate the maximum demand to be not more than 60 per cent of the total kilowatts installed, and I provide mains and switches accordingly. I have made various tests, and for baking sixpenny meat pies the energy consumption per 100 was found to be 4·8 units, or approximately 20 pies per unit. This was not on continuous working, but for batches of 100, therefore this figure is not the lowest obtainable. I shall have a better opportunity shortly of taking further tests and will make the results known. I agree with the necessity of standardizing the dimensions of heating elements so that these can be stocked by local

contractors. I do not think we shall see many cooks make these adjustments themselves. I am pleased that Mr. Nobbs agrees with me on the question of co-operation and the desirability of employing engineers who are familiar with "kitchen talk."

Mr. Hardie's early experience with electrical cooking apparatus in restaurants should not, in my opinion, be looked upon with disfavour, but as a lesson of what not to do in the future. He will have gained valuable information as to the application of electricity for such purposes and, if all details were carefully recorded, can build up a successful campaign from his experiences. Is this not already showing itself by his various electric kitchens running and in course of erection? The rate charged for electricity in Newcastle is $\frac{3}{4}$d. per unit, and we find no difficulty in competing with gas at 2s. (pre-war price) per 1,000 cubic feet. The effect of hot-plate troubles can be greatly minimized by the use of self-contained utensils. Although the paper does not deal with domestic apparatus, I suggest that Mr. Hardie should supply a self-contained kettle with his cookers, and I venture to think he will not hear many complaints about that early morning cup of tea. The restaurant referred to as using gas-rings for boiling has, I understand, decided to extend electrical apparatus to a number of its branches and to use self-contained utensils and few hot-plates. I fully endorse Mr. Hardie's remark that with electricity we can not only do everything that gas can do, but also do it better.

The views given above on Mr. Hardie's early experiences also apply to Mr. Smith's, and I hope he also has benefited by them. His reference to stews and frying, I presume, apply to the shipyard kitchens, where undoubtedly large quantities are provided; this is therefore certainly a case for self-contained utensils. It is essential as one of the first steps to reliability to fuse each section of a cooker separately. It may interest Mr. Smith to know that I pass every piece of cooking apparatus through what I call the drying-out stage, by putting all switches on the "low" position—all elements in series—for several hours before connecting the earth wires. I find that this removes all trace of surface leakage. I do not think a chef would appreciate his cookers being some distance apart to satisfy a station engineer's desire to balance the load. If it is not possible to balance the cookers against some other load, I should be inclined to connect one on the positive side and the other on the negative and to earth each cooker separately and connect their cases by a heavy wire as a precaution against stray earths. I am interested to hear Mr. Smith's views on top and bottom heating. My experience has been more successful with side heating, except of course the larger baker or pastry ovens, which are provided with crown and sole elements in all decks. I think I referred to the saving in labour with electrical cooking in advantage No. 3 in the paper.

I am pleased to hear that Mr. Henderson is interested in the subject of electric baking, and that he realizes its advantages; an outsider's opinion is always acceptable. Not knowing the lines on which his experiments are working, I cannot criticize his method, but I gather that the biscuits in the wet state are apparently placed too close to the elements in the first stage, and that the travel is not long enough to allow the steam to evaporate. Certain classes of biscuits require special attention, and biscuit ovens are in some cases made with a travel as long as 60 or 70 feet. It is often found necessary to generate steam in bakers' ovens, by placing a water bath at the bottom, or by circulation, but these ovens are mainly used for baking bun dough, etc.

Mr. Mears and many other speakers have shown great interest in the load curves, and I therefore propose to deal with them later as one item in my reply to the Newcastle discussion. It may interest Mr. Mears to know that in each of the installations referred to, and in other large kitchens in Newcastle, the apparatus has been purchased by the consumers. No hiring scheme is in operation for this size of plant and I do not see the necessity at present of establishing one. There is considerable business in every city to be secured if it is only taken up on a proper basis.

I should like to inform Mr. Wood that I am quite satisfied the paper has created interest and, I hope, helped to strengthen the views of station engineers on the possibilities of electrical cooking. I agree with him that the question of the design has not been closely gone into. As I have already pointed out, to have dealt with that side of the subject would have resulted in a very long paper, and it was therefore omitted. I am pleased to have Mr. Wood's views on the subject of standardization, and I agree with him that the present is the most fitting time to establish definite sizes or dimensions. Opportunities of securing reliable information of the performance of electrical cooking apparatus on board ship are so rare that I am afraid the matter will have to be postponed until, at least, after the War.

DISCUSSION ON "GAS FIRING BOILERS."*

Yorkshire Local Section, 15 January, 1918.

Mr. C. N. Hefford: I rather gather that the main object of this paper is to assist engineers who are already connected with coke-oven processes or iron works where they possibly have already got waste gas and are either dealing with it or anxious to use it in some form or other. I do not draw any information from it which would encourage one to go in for steam-raising from gas-fired boilers where one had to consider the obtaining of the gas purely for the purpose of heating the boilers. I am surprised to find that the extra heating surface that would be required to generate steam from gas-fired boilers is comparatively small compared with what we have to provide for in coal-fired boilers. I expected to find a much greater difference. When figures are quoted for gas-fired boilers indicating an evaporation of $5\frac{1}{2}$ lb. per square foot of heating surface, it must be admitted that these compare favourably with results obtained with the usual low-grade fuel consumed in generating stations. I expected to have to consider the provision of considerably more boiler power than that. It is very difficult for electrical engineers to follow and keep as closely in touch with scientific developments as they possibly ought to do. Already in addition to being electrical engineers we have to be mechanical engineers and civil engineers, and apparently we must be gas engineers; and I suppose we shall be chemists also before long. What would be very useful to the station engineer would be a continuation of this paper that would take the form of how an expert like the author would proceed to deal with the problem of generating, say, possibly 2,000 million pounds of steam per annum from gas-fired boilers, his object being primarily to produce steam. That is to say, what investigations would he make with a view to deciding upon a suitable by-product to produce, and what extra capital charges, if any, would be incurred in the provision of the necessary additional plant, taking into consideration the handling of large quantities of coal, with the necessary sidings and handling apparatus, and of course assuming also that such a steam-raising plant could not be accommodated in any large centre of industry, but would have to be remote from the town under consideration and would be situated probably adjacent to a colliery or wherever the process could most suitably be carried out, the energy being ultimately transmitted to the town in the form of electrical energy? There will have to be an enormous saving in the cost of generating electricity to justify the removal of central stations from the districts to be supplied.

Mr. E. Harris: I consider that gas-firing for steam boilers is particularly a question of utilizing the waste gases which are a by-product from blast furnaces and coke ovens, rather than of using the gas from producers especially installed. The bulk of our large steam users are situated in or near the centres of our cities where it would be difficult to find room for large gas-producing and by-product plants. This and other disadvantages largely prohibit the use of gas for such a purpose. Some years ago I was engaged in the manufacture of gas producers and furnaces, and in several cases we had to apply gas-firing to steam boilers. I know of very few of these installations that are at work at the present time. I believe that Messrs. Brunner, Mond & Co. and Messrs. Robert Heath & Sons of Stoke-on-Trent have gas producers for such a purpose and extract the by-products, which no doubt has been a profitable undertaking. A company has been in existence in South Staffordshire for the manufacture and distribution of producer gas, but I have no knowledge of what the gas is used for or the results obtained, and I should therefore be glad if the author could enlighten us on that point. What interests most of the steam users in the West Riding of Yorkshire are actual working results, showing (1) the fuel efficiency in the steam boilers per ton of coal gasified; (2) the evaporation from a large-sized Lancashire boiler of 8 ft. 6 in. or 9 ft. diameter by 30 ft. long; (3) the cost of fuel and labour to evaporate each thousand gallons of water; (4) the market value of the by-products per ton of coal gasified. In the Yorkshire and Lancashire textile trades a large amount of steam is used for dyeing, steaming, and heating purposes, which causes rapid fluctuations in the steam requirements; so that when we take into consideration the heat units contained in these respective types of boilers, it is found that the Lancashire type of boiler is more suitable for most of the textile trades and it is questionable if any ground space could be saved by using water-tube boilers. My experience of gas-firing for Lancashire boilers is the small evaporation and inability to deal with sudden fluctuations as compared with the best method of firing with mechanical stokers. This is one of the chief reasons why gas-firing for steam boilers has been abandoned in many cases. In my opinion if the boiler plant at a large electric light station were fired by gas, it would necessitate at least double the boiler power required for direct coal-firing. I should like to ask the author the following questions: (1) Would he recommend the installation of gas producers to fire large batteries of boilers with gas? (2) With what size of plant would it pay to use gas-firing? (3) What class of fuel does he recommend as the most suitable for gas producers? (4) Is there any installation of boilers fired from producer gas in connection with by-product recovery plant in this part of the country? It is generally admitted that gas-fired water-tube boilers are more satisfactory than gas-fired Lancashire boilers. With regard to using colliery refuse such as coke dust, pond settlings, shale, etc., as is sometimes advocated, I think it will

* Paper by Mr. T. M. Hunter (see pages 57 and 163).

be found that most collieries use all their waste materials at present with modern firing appliances.

Mr. W. Hartnell: I have had considerable experience with boilers. Some years ago on calculating the amount of water evaporated per hour per square foot of heating surface per pound of coal burned per hour, I was surprised to find that such different types of boilers as the locomotive, the vertical, and the Lancashire gave nearly the same results. Thus on drawing a curve the base lines of which represented the number of square feet of heating surface per pound of coal burned per hour in various boilers, and the corresponding verticals the pounds of water evaporated per hour per square foot of heating surface, a curve could be drawn nearly coinciding with the tops of the verticals. By means of such a curve the evaporative value of different gas fuels or coals although tested in different boilers can be practically compared with each other when the total heating surface and fuel burned per hour in each case are known. In the case of a textile machinery works near Rochdale, where Mond gas producers were supplying vertical gas engines, thd Staffordshire coal required was $1\frac{1}{8}$ to $1\frac{3}{4}$ lb. per horse-power per hour. There is an example near Barnsley on a large scale of the economical use of waste coke-oven gases for fuel by the Yorkshire Waste Heat Company. The coke ovens are of the most modern construction and connected to the latest appliances for recovering by-products. At the Farnley Iron Works near Leeds there is a Mond gas producer and ammonia-recovery plant arranged by the late Mr. Mathieson. The gas is used for gas engines driving dynamos which supply all the power and lighting; the gas is also used for heating the ovens in which the glazed bricks, etc., are burned.

Mr. E. Balmford: On page 63 the author refers to the fixing of projecting pieces or rings of angle iron on the boiler as a means of increasing the heating surface. It appears to me, however, that if this method is adopted on water-tube boilers, either the rings must be arranged parallel to the gas flow so as not to interfere unduly with the draught, in which case the effect due to them will be a minimum and probably hardly appreciable; or, if they are placed so as to be more effective as regards the transmission of heat, the draught will be so seriously interfered with that the last stage may be worse than the first. I should be very much obliged if the author would give some instances of where and how this method has been applied and what were the results obtained.

Mr. A. J. Terry: I should like to ask whether in view of the recent proposals of the Coal Conservation Sub-Committee the author would suggest that the installations therein recommended should all be situated close to the coal mines and the coal be first used in by-product ovens, the gases then being used under boilers for the generation of electricity; also whether he holds that this is the most economical way of making use of our supply of coal. Is it the best way apart from using existing coke ovens, and does he hold it to be the best plan to put down more coke ovens and work through them?

Mr. J. Shepherd: The paper describes how gas which would otherwise be wasted may be utilized; but it leaves untouched that great problem which will have to be faced shortly, namely, what is the best way to get power from coal? Should we burn the coal under boilers and make no attempt at ammonia recovery, or should we produce gas, recover the ammonia, possibly benzol, and other products, and then utilize the gas under boilers and the steam from the boilers in turbines? When we are dealing with large amounts of power it seems to me that to gasify the coal is more economical than to burn it. I know it is the opinion of recognized authorities that with a large installation utilizing all ammonia compounds and other by-products at the prices of those compounds before the War there would be a saving of something like 5s. a ton for every ton of coal gasified. Yet in the paper on page 58 the author says that he knows of no case where coal is gasified to obtain the ammonia and other products except in the case of so-called waste gas. I know that to do it on any workable scale means a large installation —certainly much larger than that which is found in any ordinary industrial works—such an installation as one would get in towns of considerable size where electricity is generated for general power purposes. In the boiler house of such an installation the cost of generation for both wages and coal is usually about three-fourths of the works cost, and that of course is the item which one must attempt to reduce. Anything like the gas-firing which I have seen, such as oil-firing, means entirely changing the conditions of the boiler house. At present this is a dirty, dusty, and uncomfortable place to work in. When burning oil (and gas) on a large scale it is quite different. One man will look after 30 boilers without any trouble, and there is no smoke, dust, or ashes to handle. There are one or two questions which I should like to ask the author. He gave a figure of 5 per cent saving in radiation when boilers are enclosed in a boiler house. I should like to know if this is an ascertained figure, or only estimated. Again, elsewhere in the paper the author gives the maximum superheat as 85 degrees C. I should like to know why 85 degrees is said to be the highest which is economical. That gives a total temperature of only 500° F. with ordinary pressures. As anyone who has used turbines knows, it is necessary to get something over 600° F. if one wants to get the greatest economy with even ordinary commercial plant.

Mr. T. M Hunter (*in reply*): This paper was written to assist engineers who are actually working gas-fired boiler plants at present, and for the benefit of engineers who have to specify such plants, to give them an idea of what they ought to specify and what it is reasonable they should get. Mr. Hefford and one or two other speakers have sketched out another very interesting paper which I might have written, on the "Production of Gas." I found that it was quite a wide enough subject to deal with the combustion of gas, keeping quite away from the question of the production of gas. There is one point I should like to make in regard to what Mr. Hefford has said about transmission losses. Transmission of electricity is very expensive, but transmission of gas is in comparison cheap. The losses on transmission of gas are very

small. I believe the figure given in America for favourable cases is something like 0·5 per cent, and for cases that are not so good up to about 2 per cent loss in transmission. In America they sometimes transmit gases for 100 miles or so, and under high pressure. If gas were generated outside the towns and transmitted in pipes to the existing power stations, these stations could be used economically, without much additional capital expenditure, in comparison with the expenditure which would have to be incurred if new stations had to be erected near collieries.

Mr. Harris has said that I have been speaking only about the use of waste gas, especially blast-furnace gas. A blast-furnace owner will say that his gas at the present moment is not a waste product, but is a very valuable commodity. If we take the price of coke at 30s. a ton, and consider a plant where one ton of coke is used per ton of iron made, half of the calorific value of the coke comes out of the furnace in the gas, so that the gas coming out is worth 15s. per ton of iron made. The distribution of the gas is as follows: 1s. 6d. for all losses, heating the blast about 4s. 6d., and gas available for boiler-firing purposes about 9s. These figures give an idea of the amount of gas available and the value put upon it by the owner at a blast furnace. In South Staffordshire the Mond plant distributes gas over a large district. At Wolverhampton I believe the present price is 5d. per 1,000 cubic feet. It is mostly used for heating in furnaces, in small works where they make chains and other small articles by hand. It would not pay to fire a boiler with gas at 5d. per 1,000 cubic feet if the gas were of 1·15 therms per cubic foot. The price would have to be 1½d. or 1¼d. per thousand cubic feet to allow it to compete with coal at 18s. per ton.

We cannot expect a gas producer plant to take peak loads at a power station. It can only give a steady output. It is not possible to press a producer plant. We must have some other method for taking the peak loads. If we had sufficient producers to take the peak loads, the capital charges would swamp the whole scheme.

The provision of superheated air is very important with regard to gas-firing, as it is with coal-firing. In this country we have done little in this direction. In Belgium and on the Continent generally they are very far ahead of us. I heard the other day from a British manufacturer that he had supplied to the Ougrée Works in Belgium, preheaters for heating the air to burn cleaned blast-furnace gas with Terbeck burners in water-tube boilers. At the outbreak of War he was on the point of delivering a large repeat order, while engineers in this country have hardly begun to think about the subject at all.

I was very interested in Mr. Hartnell's reference to the waste-heat installation of the Yorkshire Waste Heat Company. I had to do with the gas burners fitted to the boilers there, which burn coke-oven gas. It is quite a show installation and has been very successful. The average working efficiency is 82½ per cent for the Stirling boilers and superheaters. No economizers are fitted.

Mr. Balmford spoke about the use of metal projections in boiler tubes. Interesting experiments were made some years ago by putting metal studs into the flue of a boiler, projecting a considerable distance into the gas, and just screwed through the plate of the boiler. These added considerably to the heat transmitted per hour by the boiler flue. I do not think that these studs have been used commercially, but I believe that the method is right.

One of the largest installations of by-product producer plants in the country is at Runcorn. The Castner Kellner installation runs mostly with gas engines. Up to about some seven years ago it was run with gas-fired boilers. Gradually they used gas engines more and more. I hear that now they are adding steam-turbine plant and are again going to use much of their gas in boilers in addition to what they are using in gas engines.

PROCEEDINGS OF THE INSTITUTION.

601st ORDINARY MEETING, 22 NOVEMBER, 1917.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 8th November, 1917, were taken as read, and were confirmed and signed.

Messrs. F. A. Bond and T. Stevens were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Members.

Baker, Charles John.
Kristiansen, Magnus Lauritz.

Associate Members.

Brown, Clifford L.
Ellis, Richard Garratt, Lieut., R.E.
Henderson, David Cecil.
Jackson, Harold Walter.
Kerr, Henry.
Miller, John Francis Xavier.
Nicholas, Samuel William, Lieut., R.E.
Parker, Will Herbert.
Ruderman, Louis Lingg, Staff Sergt., R.E.
Souden, Frederick Howard.
Thompson, Frank Arthur.
Trice, Thomas Henry.
Turner, Samuel, Lieut., R.F.C.
Wimalasurendra, Devapora Jayasena.
Winkworth, Leonard Stuart, 2nd Lieut., R.E.

Associates.

Bales, Frederick George.
Blake, George Gascoigne.
Leete, Ernest.
Michie, Arthur Cumming.

Graduates.

Bingham, James Herbert, Lieut.
Elphick, Eric de Bock.
Flanagan, Joseph.
Moules, John Francis.
Muir, Charles Alfred W., Lieut., R.N.
Nierses, James Sydney.
Rose, John Allardyce.
Rowse, Edwin John.
Wybrow, Sidney George.

Students.

Aldereguia, Feliciano.
Arrowsmth, Sydney John.
Ayre, Nedville V.
Baerlein, John Emanuel da Cunha Guerra.
Brock, Harry.
Bulley, Howard Northcote.
Cannon, Hugh Stanley.
Cheesman, Herbert.
da Silva, Pery Roma C.
Deshpande, Shankar Balwant.

Students—continued.

Edwards, Llewlyn.
Golé, Sadashiva Mahadeo.
Harben, John Edward.
Hayne, Edwin Tufnell, Flight Sub-Lieut.
Humfress, Eric George.
Kelly, James.
Knobel, Johann Ludwig.
Lane, Gerald Nassau S.
Mantle, Rowland Shelley.
Morrow, George Leslie.
Munday, Sydney George.
O'Neill, James Francis.
Orchard, Herbert Leonard.
Parr-Dudley, Eric Arthur.
Taylor, Alfred Thurston.
Taylor, George Edmund.
Terry, Thomas William.
Thomas, Leonard.
Waters, Fred.
Watson, Thomas.
Whitehead, John, 1811 Pte.

TRANSFERS.

Associate Member to Member.

Armitage, Arthur.
Arthur, Henry Herbert.
Nassau, Thomas D'Arcy.
Wood, William.

Graduate to Associate Member.

Ahmed, Abdel Aziz, M.Sc. (Eng.).
Bloore, Thomas.
Das, Bhubanananda, B.Sc.
Hickie, Charles Sinclair, 2nd Lieut., R.F.C.
Medforth, George Taylor.

Student to Associate Member.

Barlow, Ernest Bernard.
Clement, Luis Felipe.
Gill, David.
Hartley, John Barker.
James, Ernest George.
Macklin, Roderic William, Captain, R.G.A.
Mowat, John Watt.
Searle, Arthur Mackenzie.
Shaw, Walter Howard.
Tuppen, Harold Richard, Captain, M.C., A.S.C., B.Sc.
Wenger, Theodore L.

Student to Graduate.

Bostock, Clement Wildsmith.
Collyer, George, 2nd Lieut., R.E.
de Moura, Silvio Neves.
de Paiva, Alfredo Teixeira.
Noor-el-Deen, Youssif.
Pernet, Frederick Harry.
Sharrock, Charles Frederic Keith.
Singh, Prem.

The President announced that the Council had unanimously elected Professor Augusto Righi of Bologna University to be an Honorary Member of the Institution.

A paper by Mr. T. M. Hunter, M.A., B.Sc., entitled "Gas Firing Boilers" (see page 57) was read and discussed, and the meeting adjourned at 7.55 p.m.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 56. APRIL, 1918. No. 273.

SWITCHGEAR STANDARDIZATION.

By CHARLES C. GARRARD, Member.

Paper first received 22 *November*, 1917, *and in final form* 8 *January*, 1918; *read before* THE INSTITUTION, 21 *February*, *before the* BIRMINGHAM LOCAL SECTION, 20 *February*, *and before the* NEWCASTLE LOCAL SECTION, 11 *March*, 1918.)

SUMMARY.

General principles underlying standardization.

Standard test pressure for switch and controlling gear.

Conductivity of current-carrying alloys: specifications of cast brass and gunmetal.

Knife switches: millivolt drop at contacts.

Suggested standards for back connection studs and nuts.

Oil switches and circuit-breakers: urgent necessity of standard oil-switch rules in view of the position in foreign countries; breaking capacity; connection between breaking capacity and quantity of oil.

Resistance and reactance type of oil circuit-breakers.

Length of break of oil switches.

Single and multiple tanks on oil switches.

Amount of oil required for oil switches.

Speed of operation of oil circuit-breakers.

Air-break circuit-breakers: millivolt drop at brush contacts.

Cut-outs: National Electric Code enclosed cut-outs; short-circuit tests on cut-outs; time element of cut-outs; determination of normal fusing current.

Resistance wire: suggested British copper-nickel standards.

Motor starting-gear: liquid starters.

Copper strip connections of switchboards: suggested standard sections; temperature rise; millivolt drop of bolted contacts.

Switchboards: cellular principle; suggestions put forward by Swiss Electrotechnical Society.

Lightning protective gear: horn gaps; choking coils; lightning arresters.

Of all departments of electrical engineering, switchgear is perhaps the one whose development is in the greatest state of flux and in which more changes and improvements are continually taking place, and will continue to take place, than in any other. Under these circumstances, at first sight, it may be thought that it is a very unfit subject for standardization. Such a conclusion, however, betrays a want of appreciation of the true and best meaning of standardization. Standardization properly understood is essentially a co-operative action on the part of the designers and manufacturers concerned in order that the best product may be produced in the shortest time and with the least expenditure. To attain this end each party throws into the common stock his knowledge and experience; the old-fashioned secretive policy is abandoned, it being recognized that in this, as in so many other departments of national life, the purely individualistic policy must give way to the more enlightened and, in the long run, better paying one of mutual help and combined action.

Apart, however, from the need of such a change in our methods, if we are to maintain our position in the world's engineering market in the future, it must be recognized that it is also necessary if we are even to put ourselves upon an equality with other countries. Switchgear standardization has already had considerable attention paid to it in America, Switzerland, and Germany, and one object in view in submitting this paper is to call attention to this fact and to urge that such steps be taken as will put an end to this unsatisfactory state of affairs.

The authority for engineering standardization in this country is the Engineering Standards Committee. According to the 1917 report of the Committee no single standard specification dealing with any form of switchgear has been issued. Specifications dealing with wall plugs and ceiling roses have, it is true, been prepared, but these come under the domain of accessories and not that of switchgear properly understood. In fact there does not seem to be any suitable organization within the Standards Committee to deal with such work. There is a sub-committee, with a number of panels, for dealing with electrical accessories. But heavy modern switchgear is not properly classed under this designation. It would appear that there is urgent need for the formation of a special sub-committee to deal specifically with switch and controlling gear.

This sub-committee could arrange for its special panels for the various subjects and there need be very little, if any, overlapping of the existing electrical accessories sub-committee and panels.

In the following remarks it is desired to explore to some extent the ground indicated, and to discuss a number of matters in connection therewith.

Standard Test Pressures for Switchgear.

In the various specifications being issued by the Engineering Standards Committee test pressures are enumerated for the articles dealt with. It would, however, be better if a standard test pressure could be agreed upon applicable to all switch and controlling gear. This should be higher than the corresponding test for machinery. The American Standardization Rule No. 500 specifies for machinery a test pressure equal to 1,000 volts plus twice the normal; for switches and control apparatus above 600 volts, however, rule No. 509 calls for 2,000 volts plus $2\frac{1}{4}$ times the rated voltage. This latter test is very good and reasonable, and moreover is a sufficiently high one for any form of switchgear. We cannot do better than adopt it.

Conductivity of Current-carrying Alloys.

The standardization of copper has already received considerable attention from the Engineering Standards Committee, and a similar standardization of the other current-carrying materials used in switchgear should be made. These include brass, gunmetal, and phosphor bronze. In passing, it may be mentioned that the whole subject of copper alloys stands in urgent need of standardization. The percentage composition of a "brass" casting is, for example, a very nebulous quantity. Even the Standard Specification (No. 35) which gives the standard dimensions for brass rods is but little used by the trade. There is no doubt but that electrical engineers, in common with all other users of brass, would heartily welcome standardization along the lines indicated. The following specification for brass castings which has been used in want of a better one may be of interest: —

Specification for Brass and Gunmetal for Castings.

Brass.—Castings must be clean and free from sand and without fins, gits, or blow-holes. No trace of iron or nickel must be present. The composition should be within the following limits:—

Copper .. 66 to 75 per cent
Remainder zinc, impurities not to exceed 2 per cent of total weight

Gunmetal.—Must be of similar general quality to the brass above specified. Particular care must be given to freedom from blow-holes in order to secure good electrical conductivity. Composition:—

Copper	.. .. ..	88 to 90 per cent
Tin	.. .. ..	10 to 11 ,,
Zinc	.. .. ..	1 to 2 ,,

Knife Switches.

A standardization of the length of break, distance between the centre lines of the poles, sizes of terminals, current density in the material, and general style of construction is very necessary. Suggested values for some of these have been already given by the author elsewhere.* At the present time various authorities

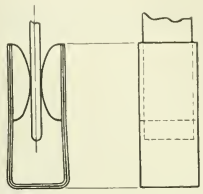


Fig. 1.—Controller-finger type of switch contact.

have fixed their own standards, necessitating special manufacture. In addition, numbers of obsolete requirements are still insisted upon in certain quarters. For example, the condition that the hinge of a knife switch should not carry current still survives. This should be obviated in future. As regards the current density of surface contacts, it is not desirable to fix limits as to this, as apparently very high surface densities sometimes yield very good results. There is much to be said in favour of the type of switch contact illustrated in Fig. 1.

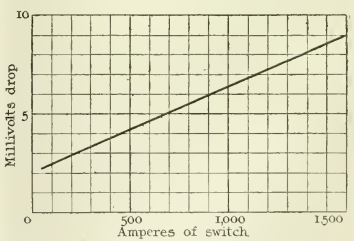


Fig. 2.—Millivolt drop at the jaws of knife switches.

The explanation would appear to be that with the ordinary form of flat contact the current really only passes at a single or a few points. With the controller-finger type, however, a definite line contact is obtained. A standardization of the millivolt drop, at contacts, however, would be a very good thing, and, as this is a direct measurement of the capability of the device to make contact, has much to recommend it. The values given in Fig. 2 are founded on actual practice in good class work.

* "Electric Switch and Controlling Gear," p. 59.

Current-carrying Back Connection Studs for Switches, Etc.

Considerable variations exist at present in the practice of different manufacturers in regard to back connection studs, more especially as regards the screw threads adopted. The type of thread used must be determined more from considerations of electrical conductivity than from mechanical ones. The Whitworth screw threads, for example, on the larger sizes have too coarse a pitch which cuts unduly into the cross-section of the rod. A standardization of these screw threads, as also of the corresponding nuts, is very necessary. The particulars given in Table 1 have been found suitable by the author and are put forward as a basis of discussion.

Table 1.

Suggested Standards for Back Connection Studs for Switches, Etc.

Current in Amperes	Rod Diameter of Studs in Inches	Screwing of Stud
3,000	2	11 threads per inch, Whitworth-shaped thread
2,500	$1\frac{3}{4}$	,, ,, ,,
2,000	$1\frac{5}{8}$	,, ,, ,,
1,800	$1\frac{1}{2}$	,, ,, ,,
1,500	$1\frac{3}{8}$	,, ,, ,,
1,200	$1\frac{1}{4}$	,, ,, ,,
1,000	$1\frac{1}{8}$	,, ,, ,,
800	1	,, ,, ,,
600	$\frac{7}{8}$	,, ,, ,,
400	$\frac{3}{4}$	,, ,, ,,
300	$\frac{5}{8}$	$\frac{5}{8}$ in. Whitworth standard 11 threads per inch
200	$\frac{1}{2}$	$\frac{1}{2}$ in. ,, 12 ,,
150	$\frac{7}{16}$	$\frac{7}{16}$ in. ,, 14 ,,
100	$\frac{3}{8}$	$\frac{3}{8}$ in. ,, 16 ,,
75	$\frac{5}{16}$	$\frac{5}{16}$ in. ,, 18 ,,
50	$\frac{1}{4}$	$\frac{1}{4}$ in. ,, 20 ,,
25	0·184 to 0·186	No. 2 B.A.

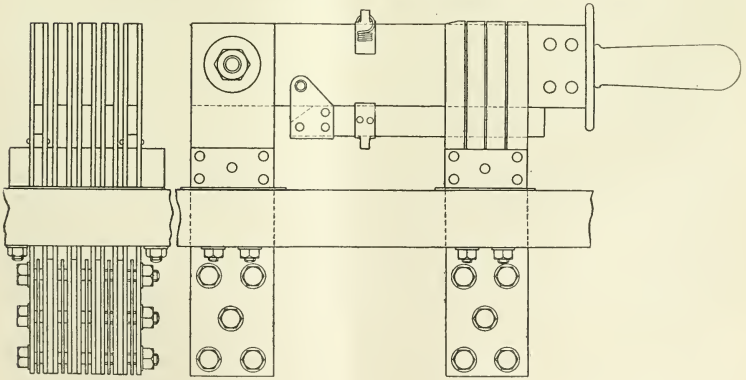


Fig. 3.—Large knife switch with strip back connections.

It will be seen that with the exception of the smallest size the Whitworth form of thread has been adhered to. In all sizes, however, above $\frac{5}{8}$ inch diameter the pitch is smaller than that of the corresponding diameter Whitworth standard screw. It would not be desirable

to standardize studs above 3,000 amperes. For these very large sizes the form of construction illustrated in Fig. 3 is to be preferred. It will be seen that strip connections are riveted and soldered into the switch block. These constitute a better electrical connection and, moreover, are cheaper to construct in these sizes than studs would be. It may be added that diameters of contact studs have been standardized by the Verband Deutscher Elektrotechniker up to 1,500 amperes.*

Connection Nuts.

The nuts for making the connection between the studs and the connection strips must be thinner than

Table 2.

Suggested Dimensions of Standard Hexagon Brass Nuts for Switchboard Connections (cf. Fig. 4).

Amperes	Diam. of Screw	Threads per Inch	A	B	C
	in.		in.	in.	in.
3,000	2	11	$3\frac{5}{32}$	$3\frac{5}{8}$	$\frac{6}{8}$
2,500	$1\frac{3}{4}$	11	$2\frac{3}{8}$	$3\frac{3}{16}$	$\frac{6}{8}$
2,000	$1\frac{5}{8}$	11	$2\frac{3}{64}$	$2\frac{31}{32}$	$\frac{1}{2}$
1,800	$1\frac{1}{2}$	11	$2\frac{1}{8}$	$2\frac{25}{32}$	$\frac{1}{2}$
1,500	$1\frac{3}{8}$	11	$2\frac{7}{32}$	$2\frac{5}{64}$	$\frac{1}{2}$
1,200	$1\frac{1}{4}$	11	$2\frac{3}{64}$	$2\frac{23}{64}$	$\frac{1}{2}$
1,000	$1\frac{1}{8}$	11	$1\frac{57}{64}$	$2\frac{7}{32}$	$\frac{1}{2}$
800	1	11	$1\frac{43}{64}$	$1\frac{61}{64}$	$\frac{1}{2}$
600	$\frac{7}{8}$	11	$1\frac{31}{64}$	$1\frac{45}{64}$	$\frac{7}{16}$
400	$\frac{3}{4}$	11	$1\frac{19}{64}$	$1\frac{1}{2}$	$\frac{3}{8}$
300	$\frac{5}{8}$	Whitworth	$1\frac{9}{32}$	$1\frac{17}{64}$	$\frac{3}{8}$
200	$\frac{1}{2}$	Whitworth	$\frac{29}{32}$	$1\frac{1}{16}$	$\frac{3}{8}$
150	$\frac{7}{16}$	Whitworth	$\frac{58}{64}$	$\frac{61}{64}$	$\frac{5}{16}$
100	$\frac{3}{8}$	Whitworth	$\frac{45}{64}$	$\frac{13}{16}$	$\frac{5}{16}$
75	$\frac{5}{16}$	Whitworth	$\frac{29}{64}$	$\frac{11}{16}$	$\frac{1}{4}$
50	$\frac{1}{4}$	Whitworth	$\frac{23}{64}$	$\frac{29}{64}$	$\frac{1}{4}$
25	No. 2	B.A.	Use standard nut		

Table 3.

Suggested Standard Thin Hexagon Brass Nuts for Intermediate Switchboard Connections (cf. Fig. 4).

Size	A	B	C	Threads per Inch
In.	In.	In.	In.	
$1\frac{1}{8}$	$1\frac{55}{64}$	$2\frac{5}{32}$	$\frac{1}{4}$	11
1	$1\frac{39}{64}$	$1\frac{61}{64}$	$\frac{1}{4}$	11
$\frac{7}{8}$	$1\frac{31}{64}$	$1\frac{45}{64}$	$\frac{1}{4}$	11
$\frac{3}{4}$	$1\frac{19}{64}$	$1\frac{1}{2}$	$\frac{1}{4}$	11

standard Whitworth nuts. This is necessary in the first place from considerations of space, which is naturally limited at the back of switchboards. The chief point,

* *Elektrotechnische Zeitschrift*, 1910, vol. 31, p. 326.

however, is that it must be possible to make a neat job of the multiple strip connections attached to the studs so arranged that they occupy the minimum of space consistent with efficient ventilation. The best arrangement is to make the spacing nuts double the thickness of the standard connection strip (cf. page 223).

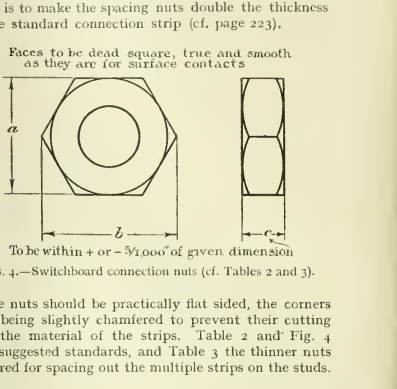


Fig. 4.—Switchboard connection nuts (cf. Tables 2 and 3).

The nuts should be practically flat sided, the corners only being slightly chamfered to prevent their cutting into the material of the strips. Table 2 and Fig. 4 give suggested standards, and Table 3 the thinner nuts required for spacing out the multiple strips on the studs.

Oil Switches.

The standardization of oil switches is at the moment receiving attention and will therefore not be discussed at great length here. It will, however, not be out of place to call attention to the considerable amount of work which has taken place in other countries. This has had the result, before the war, of greatly assisting our foreign competitors' export trade in switchgear.

The action of heavy-duty oil switches is still really very little understood. The buyer, therefore, in choosing which switch to purchase is greatly influenced by the opinion he holds of the technical knowledge of the manufacturer offering the goods. The German manufacturer, for example, fortified with a set of carefully worked-out standards, was at a great advantage as compared with the British manufacturer who had nothing similar to put forward. Happily we are within measureable distance of an alteration of this state of affairs.

The German or "V.D.E." Rules referred to, not only include a set of standards as regards the construction of the switches themselves, but also a number of suggestions to guide the operating engineer in his selection of a suitable switch having regard to the possible value of the short-circuit current at the situation where the switch is to be used. Such a set of rules is of the utmost service.

Referring again to the switches themselves, the most important point in their standardization is that of their rating in terms of breaking capacity. It is obvious that such a rating can only be reliable if based upon actual experience. It must be confessed that many of the ratings of oil switches which are guaranteed by various manufacturers are merely "intelligent guesses," as means for making such tests are as a rule not available. In Appendix I will be found references to a number

of such tests which have been published. The opportunities for making such tests in this country are, however, very few. The engineers in charge of our large supply undertakings are naturally chary of undertaking the not negligible risks entailed in such tests. Yet such systematic tests are necessary if progress is to be made in a reasonable time. In this connection it is noteworthy that recently, and since the war, the Allgemeine Electricitäts Gesellschaft of Berlin has built a special laboratory for the specific purpose of testing oil switches. This has been described recently in the technical Press: * it is worthy of the attention of the Institution that while last year the British Government, through the Department for Scientific and Industrial Research, encouraged an investigation on the subject of "Switching and Arcing" to the extent of a few hundred pounds, at precisely the same time this Berlin firm was building a special laboratory for exactly the same research at a cost probably one hundred times as great.

The question will be asked: Can this handicap under which we are suffering be removed? If left to the individual firms it is improbable that any single concern will go to the great expense of establishing and running a research laboratory on the necessary large scale. Moreover, to the author it appears that this would be much better dealt with by co-operative action between the industry as a whole and the Government. This action could take the form of the establishment of a national high-tension research and standardizing laboratory which could deal with such problems as this and those mentioned on page 226 under the heading of lightning arresters. The equipment, staffing, and running of an efficient laboratory on the necessary scale mean something altogether different from anything yet attempted in this country. The very best engineering talent should be secured for its direction, and considerable financial resources would have to be available for the large scale experiments necessary.

Maximum possible breaking capacity of an oil switch.—The leading consideration to be borne in mind when installing an oil switch on a large system is the maximum value of kilovolt-amperes which it will have to rupture. On large modern plants this becomes very large, and there can be little doubt that to some extent the value of short-circuit has increased more quickly than the corresponding improvements in the oil-switch construction. The use of reactances to limit the short-circuit current has now become recognized as essential for continuity of supply and it is of interest to discuss the conditions imposed upon such sectionalizing of large systems by the present state of development of the oil switch. While it is no doubt possible to construct oil switches for any duty whatsoever, yet if too great a demand be made upon them they become so large and unwieldy that it is better to adopt other means of limiting the short-circuit current and thus enabling the relatively smaller switches to be used. It is suggested, therefore, that a maximum breaking capacity of 500,000 k.v.a. should be regarded, at any rate with the present state of the art, as the largest short-circuit load with which any oil switch should be called upon to deal.

* *Electrician*, 1917, vol 79, p. 884

The standard rules when formulated should embrace sizes up to this value. It may be added that this maximum breaking capacity is considerably larger than any of the standards set up by the V.D.E., and would therefore constitute a considerable advantage over those rules.

Resistance and Reactance Type Oil Circuit-breakers.

The use of the two-step oil switch (Fig. 5) having a resistance or choking coil connected between the two steps has been advocated in some quarters. The Swiss Elektrotechnischer Verein in its report (see page 225) recommends this. With such a switch, on switching in the resistance is momentarily connected in series with the circuit and then short-circuited. On switching off the order of procedure is reversed; Fig. 6 is a drawing

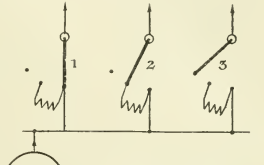


Fig. 5.—Diagram illustrating the use of two-step oil-switches having resistances, or choking coils, connected between the steps.

of such a switch. As such arrangements considerably increase the complexity of the oil switches it is very desirable to elicit expressions of opinion as to the advantages of the system and as to whether any standard specification should contain any provision for such an arrangement. Such switches may be regarded from two points of view, that is to say, switching-on and switching-off.

(*a*) *Switching-on of two-step oil switches.*—The use of the charging resistance is of value in the case of switching-in of large transformers, for preventing the abnormal rush of current which sometimes occurs. Such a current, however, lasts only for a very short time, and the only real trouble is due to the tripping of the overload release gear. This can be guarded against by a time lag on the transformer switch. For switching-in cables such double-contact switches are totally unnecessary.

Such charging resistances are also sometimes called for for switching in large motors, the object being to prevent the concentration of voltage across the end turns of the windings and consequent danger of internal short-circuit. For this purpose a non-inductive resistance is not much good but a charging choke coil should be used. It must be admitted, however, that a method such as this is rather a condonation of inferior insulation of the machine concerned. If this latter were better constructed, such special switching appliances

should not be necessary. If, however, some such safeguard is deemed to be unavoidable, then a small, adequately insulated, choke coil permanently in circuit with the machine may be used

(*b*) *Switching-off of two-step oil switches.*—The Swiss

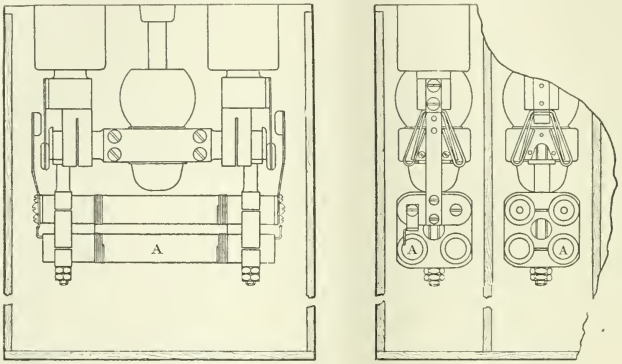


FIG. 6.—Oil Switch with Self-contained Charging Resistance.
A – charging resistance.

Electrotechnical Society base their recommendation (see page 217) of the use of such double-contact switches on their alleged capability of dealing with heavier short-circuits than single-contact switches. It is very much to be doubted whether this contention is right, and in the absence of reliable test results, made under the heaviest conditions, it should not be accepted.

To the present author the great objection to such switches is their complexity. An oil switch in a large system is subjected to such severe usage that it should be constructed in the strongest and simplest manner with as few parts to get out of order as possible. From this point of view the use of double contact switches should be discouraged.

Length of break of oil switches.—The V.D.E. rules before referred to do not set up any standard for length of break, this being left to the individual manufacturers. It is possible, by means of special constructions, to shorten considerably the length of break necessary in an oil switch. As, however, these devices come under the destructive effect of the arc every time the switch operates, it would seem a dangerous policy wholly to rely upon them.

It is better to have such a length of break that a reasonable degree of safety is secured, even if the special devices mentioned are put out of action. By length of break is meant the total length; thus if there are two breaks per phase it is the sum of the two breaks. It must be remembered also that the break does not begin until the sparking tips part company; sometimes the travel of the switch mechanism is confused with the length of break. Fig. 7 represents the average of a number of first-class modern manufacturers and may be taken as typical of present-day designs. For switches of exceptionally large breaking capacity, however, the breaks are sometimes larger than those indicated in the curve.

Single and multiple tanks on oil switches.—There is an impression in some quarters that the mere division of an oil-switch tank into three separate tanks,

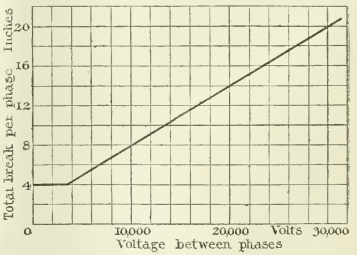


FIG. 7.—Curve connecting total length of break and voltage of oil switches.

one for each phase, is an advantage from the point of view of operation under short-circuit. Seeing, however, that the effect of this sub-division is to bring earthed metal between the phases and in closer proximity to the contacts, the effect is likely to be the other way

about. Of course in all cases for switches of any considerable size, insulating barriers should be arranged between the phases. The question as to whether a separate oil tank should be used per phase is simply, in the first instance, one of size and weight. On the larger switches a single tank becomes too unwieldy to handle. For great breaking capacities, therefore, three tanks are used, and with such switches it is better to arrange for actual concrete or brick barriers to separate the phases entirely.

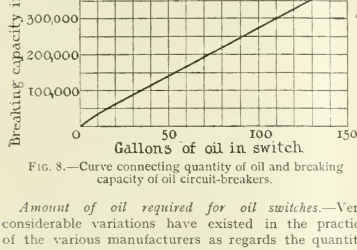


FIG. 8.—Curve connecting quantity of oil and breaking capacity of oil circuit-breakers.

Amount of oil required for oil switches.—Very considerable variations have existed in the practice of the various manufacturers as regards the quantity of oil deemed necessary for a switch of given breaking capacity. As, however, the oil is the medium for taking up the energy liberated within the switch at the instant of rupture, it is to be assumed, from first principles, that the more oil there is the greater

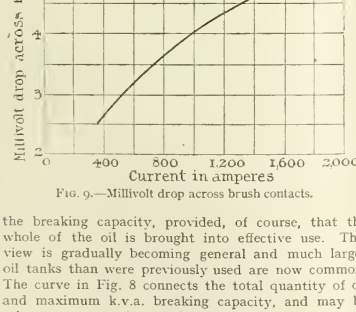


FIG. 9.—Millivolt drop across brush contacts.

the breaking capacity, provided, of course, that the whole of the oil is brought into effective use. This view is gradually becoming general and much larger oil tanks than were previously used are now common. The curve in Fig. 8 connects the total quantity of oil and maximum k.v.a. breaking capacity, and may be taken as representing good modern practice.

Speed of operation of oil circuit-breakers.—A high speed of operation is now recognized as an important factor in increasing the breaking capacity. There are two points to be considered; first, the total time required for the travel of the switch from the instant that the contacts finally part company to the completion of the travel; secondly, the initial speed at which the break contacts separate. The second is the more important, as it is of the utmost importance that the current be finally ruptured during as small a proportion of the total travel as possible. Information regarding these two points should be sufficient to define the action of the breaker in this respect. If by speed of operation is meant the actual velocity of the moving portion of the switch, it must be borne in mind that if there are two breaks per phase the circuit is being actually opened at twice the speed of the mechanism. This could be taken into account by multiplying the actual mechanical speed by the number of breaks per phase. Reference may be made to Appendix II for further discussion of this subject.

AIR-BREAK CIRCUIT-BREAKERS.

In circuit-breakers, brush contacts are usually used at a very considerably higher contact surface-density than with the jaws of knife switches. A separate standard of specific pressure drop of brush contacts is therefore required. The values given in Fig. 9 are put forward as a basis of discussion. They represent results which can be obtained by reasonably good work and which do not result in temperature rises above those suggested on page 224. A standard of breaking capacity also should be fixed analogous to that discussed under cut-outs and oil switches.

CUT-OUTS.

While the standardization of cut-outs has been carried out to a considerable extent in other countries with us practically nothing has been done. This is not to say that the subject has not been worked at. Numerous researches and papers have been published, notably those by Schwartz and James.* The Engineering Standards Committee announce, however, in their 1917 Report, the forthcoming issue of a specification for fuses for use on ships. It is to be hoped that this will be followed at no distant date by the others which are urgently needed in the interests of the industry.

One of the evils which the manufacturers of this class of article suffer under, is that cut-outs have been considered as peculiarly fit subjects for special designs on the part of their users. In this, electric supply engineers have often followed the example of waterworks and gasworks engineers in similar circumstances.

The author was informed recently by a manufacturer in the Midlands that his firm alone made over 300 different patterns of $\frac{3}{4}$ in. main gas-cocks.

Many electric supply authorities issue their own specifications for house-service cut-outs, necessitating special drawings, patterns, and tools. The same remarks apply to house-service cable boxes, main switches, and the like. It is perhaps too much to hope that all this can be swept away, within a reasonable time, simply by the issue of specifications by the Engineering

Journal I.E.E., 1905, vol. 35, p. 364, and 1908, vol. 41, p. 40.

Standards Committee. An energetic propaganda among the responsible parties will be necessary to secure the desired results. These could best be obtained probably if supply engineers could be induced to take the matter up themselves with the object of securing uniformity as regards house-service fittings. By these means very valuable information could be made available which would guide the Engineering Standards Committee in their preparation of the final specifications.

In this connection it is interesting to note that the Municipal Tramway Association has appointed recently a committee to deal with the standardization of overhead construction, which proposes to draw up specifications for every overhead fitting used in tramway work, including trolley wires and wheels. The Committee intends collaborating with the American Tramways Standardization Department and with the British Engineering Standards Committee and should provide a working model for the arrangement now suggested for dealing with electric supply fittings.

National Electric Code cut-outs.—In any review of the subject of cut-out standardization, one of the first things to be considered is the enclosed cut-out standardized by the American National Electric Code. This is completely standardized as regards dimensions, and its use is practically obligatory in America as the Code is the standard insisted upon by the fire insurance authorities there. The manufacture of "N.E.C." enclosed cut-outs has become consequently a very important industry engaging the attention of a number of specialist firms. The general use of open and protected type cut-outs, as in this country, has been impossible in America. It is true the Code contemplates open cut-outs and gives dimensions of the same. Nevertheless these appear practically never to be used. As, in spite of this, the fire hazard in this connection is not any greater with us than in the States, it cannot be said that the universal use of the relatively expensive enclosed type is justified. Nevertheless, there is a considerable field for enclosed cut-outs to meet severe conditions, and a British Standard for such should be set up as well as for the protected type. As regards open-type cut-outs, the only thing about them which need be standardized is their name, as their use should be prohibited.

The short-circuit test called for in the "N.E.C." enclosed cut-out is one of 10,000 amperes, independently of the size of the fuse. While this is a comparatively light test for a large cut-out (say, 400 amperes working current) it is a severe one for small currents (10 or 30 amperes) and one which many protected-type cut-outs will not pass. For very many purposes, however, such a severe test is quite unnecessary.

Short-circuit tests on cut-outs.—It has been generally agreed that the severity of a short-circuit test to which a cut-out is subjected may be measured by the value of the short-circuit current that would flow if the fuse were replaced by a heavy copper connection having no appreciable resistance, the electromotive force of the supply remaining constant.

In endeavouring, therefore, to arrive at a figure for the short-circuit test to insert in a standard specification, one has to consider what short-circuit current, as defined above, does actually flow in different situations in a supply network.

Schwartz and James in their paper laid it down that a short-circuit current for main fuses and distribution boards not greater than 33 times the normal fusing current corresponds to the usual conditions met with in house-service installations. This means that for a 10-ampere working-current cut-out, having a normal fusing current of 30 amperes, the short-circuit current does not exceed approximately 1,000 amperes. This conclusion is a sound one and is borne out by practice in very many cases.

Nevertheless, with the increased size of modern distributing networks, conditions do arise which are very much more severe than those formulated above. It is easy to foresee this by calculating the short-circuit currents for small cut-outs situated at the immediate ends of short feeders having large cross-sections.

This view is also confirmed in a very interesting paper issued by the American Bureau of Standards in 1916.* In order to get an idea as to the currents that might be expected under actual service conditions in case a short-circuit should occur near the customer's cut-out a number of tests were made, the results of one series of which are given in Table 4. These tests were made in the heart of the Edison three-wire distribution system, at points varying from one to six city blocks from the nearest power house. The tests were made by connecting a resistance grid across the cut-out terminals. With the switch closed, a current of about 300 amperes was taken, and at the instant of closing, the drop in volts at the cut-out was noted, and from this the current that would occur on dead short-circuit at the cut-out could be readily calculated.

TABLE 4.

Regulation Tests on Continuous-current Customer's Service: Edison three-wire system; Commonwealth Edison Company, Chicago.

Test No.	Distance to nearest Substation	Calculated Short-circuit Current
	Ft.	Amps.
1	150	26,200
2	400	107,000
3	1,500	20,000
4	600	17,100
5	1,100	9,800
6	1,300	13,200
7	1,100	25,500
8	900	87,300
9	2,300	13,900
10	3,000	13,400
11	2,350	9,800
12	3,400	8,100
13	2,600	6,100

These tests may be taken as representative of a very large part of the Edison three-wire system in the larger cities of the States.

* Technologic Paper No. 74: "Investigation of Cartridge-enclosed Fuses."

In view of the results given in Table 4 it might be thought at first that, to be on the safe side, all cut-outs should be specified to be capable of standing up to the very severe short-circuit conditions therein shown. This, however, would entail the use of much more expensive fittings than experience has shown in many cases to be necessary. In fact in probably the large majority of situations in this country nothing like the short-circuit conditions would exist as discovered in Chicago. The conclusion must, however, be drawn that with the increasing size of distribution networks the short-circuit conditions should be determined in the manner outlined above and cut-outs specified accordingly. It is also quite clear that a single rating as regards short-circuit would not be sufficient to cover the whole field; at least two types of cut-outs are necessary—one for heavy duty and one for lighter or ordinary duty.

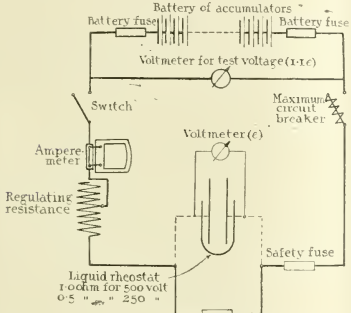


FIG. 10.—Standard cut-out test of the Swiss Electrotechnical Society.

Standard method of testing cut-outs.—The various methods adopted by the standardizing authorities of the different countries for determining the rating (as regards short-circuit capacity) all go on the same lines, that is to say, the cut-out is short-circuited across a sufficiently large source of power with the short-circuit current limited to certain values.

Fig. 10 illustrates the test specified by the Association Suisse des Electriciens * for enclosed cut-outs up to 60 amperes working current. The battery must have a voltage measured on open circuit at least 10 per cent larger than the voltage of the cut-out being tested. The liquid rheostat of the value stated in the figure is first connected across the terminals of the cut-out (the latter not being in circuit) and the adjustable resistance arranged so that for a 250-volt cut-out a current of 500 amperes flows. It will be seen that this allows for a 10 per cent drop at 500 amperes across the adjustable resistance, which corresponds to a short-circuit current of 5,000 amperes. The test fuse is then connected instead of the liquid rheostat and must rupture the circuit without an explosion or sustaining the arc.

The principle of the German (V.D.E.) rules as regards the short-circuit test is the same as the Swiss rules except that the values are different, and in Table 5 the various figures for the different countries are tabulated.

TABLE 5.

Values of Short-circuit Current specified by various National Rules for the testing of Cut-outs.

Working Current of Cut-out	Swiss	German	American (N.E.C.)	Schwartz and James
Amps.	Amps.	Amps.	Amps.	Amps.
10	5,000	4,000	10,000	990
30	5,000	6,000	10,000	1,980
60	5,000	12,000	10,000	3,960
100	—	20,000	10,000	6,600

Amount of plant necessary to be used when making short-circuit rating test on cut-outs.—Considerable discussion has taken place as to the influence upon the severity of the test of the amount of plant connected at the time the test is made. The whole of this discussion can be clarified if we take as criterion of the severity of test the value of the short-circuit current as above defined. Naturally with a small amount of plant the short-circuit current is very limited. Again if we, in any case, limit the possible short-circuit current by series resistance then, provided a certain minimum of plant is exceeded, the addition of more plant makes very little, if any, difference. It is therefore only necessary to specify the minimum of plant that shall be used. It is suggested that 100 kilowatts would be sufficient for ordinary duty cut-outs and 500 kilowatts for heavy duty ones. It should be noted that these are the minimum values; more may be necessary in order to reach the short-circuit capacity when testing the larger sizes of cut-outs.

Time element of cut-outs.—In several of the foreign standard specifications for cut-outs, periods of time are fixed within which the various cut-outs must operate. It is worth while to consider whether it would be advisable to include similar requirements in any British standards which may be issued.

The time taken to blow a fuse depends upon its size and the degree of overload. This is illustrated by the curves in Fig. 11.* It will be seen that the times taken to melt the three fuses at the normal fusing currents were about 4 seconds, 10 seconds, and 18 seconds respectively. It will also be observed that

* *Bulletin de l'Association Suisse des Electriciens*, 1910, No. 9.

* *Journal I.E.E.*, 1905, vol. 35, p. 392.

the current which gives a more or less instantaneous operation is very indeterminate, as the curves tend to rise practically vertically.

Schwartz and James suggested the following definition of "normal fusing current":—

> "The minimum current required to fuse the wire in such a time interval as shall be necessary for the wire to have attained its maximum steady temperature."

This is practically the same definition as has been adopted by the National Electric Code.

The normal fusing current can best be ascertained by plotting a curve as in Fig. 12. It will be seen that the curve approaches a vertical asymptote, the value

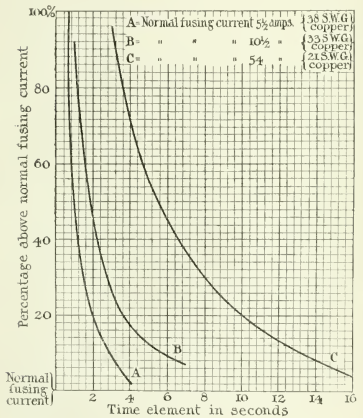


Fig. 11.—Time elements of fuse wires (open).

of which is the normal fusing current. If the normal fusing current be suddenly applied to the cold fuse a longer or shorter time will be required to melt the fuse depending on its size (cf. Fig. 11).

It follows from the above that if a definite and fixed time element be specified it would in the first place be necessary to specify a different value of time element for each diameter of fuse wire; secondly, it would be necessary to have different values of time element for open, protected, and enclosed cut-outs, and likewise different time elements for each fuse metal.

It is to be presumed that in fixing definite time elements for cut-outs those concerned have regarded them as essential in order to guard against overheating in the apparatus protected by the cut-out.

The heating of a copper conductor in series with a cut-out can easily be calculated if we neglect any cooling effect, thus obtaining the maximum possible temperature rise. The calculation can be made from the formula

$$\left.\begin{matrix}\text{Temperature rise in degrees}\\ \text{Centigrade per second}\ \ ..\end{matrix}\right\} = 0{\cdot}005 \left\{\frac{I}{c}\right\}^2$$

I being the current in amperes and c the cross-section of the conductor in square millimetres.

Considering the thinnest wires these, according to the Institution wiring rules, would have a working current density not exceeding 5 amperes per square millimetre, and the normal fusing current of the fuse would be three times the working current. This gives a temperature rise per second in the conductors with the normal fusing current flowing of 1·1 degrees C.

A current just below the normal fusing current could flow indefinitely and whether the conductor will reach

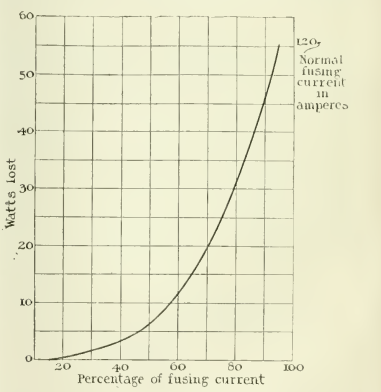


Fig. 12.—Curve for determining normal fusing currents of a cut-out.

a dangerous temperature will depend upon its heat dissipating capacity. It is obvious that to specify a time element for the fuse would not add to the margin of safety. The point is that the factor of safety as regards heating of the conductor is conditioned wholly by the value of the normal fusing current, as a current just below this value can flow continuously.

Turning to larger conductors the current density would be approximately 2 amperes per square millimetre and the normal fusing current double the working current. These figures correspond to a temperature rise of 0·08 degree Centigrade per second. The actual temperature rise of a conductor having a current flowing through it indefinitely in value just below the normal fusing current could only be determined satisfactorily by experiment. The Institution Wiring Rule No. 98 *b* requires that fuses "must be so proportioned to the

current to be carried that no conductor protected by them can be raised in temperature above that specified in Rule 44."

It would be very desirable if directions could be issued to guide the user in applying this rule. As it stands, the requirement simply begs the question. It is to be hoped that some information on this subject may be forthcoming before long. At any rate to specify the time element of a cut-out does not serve any useful purpose and it is suggested it should not be done.

Resistance Wire.

For the construction of starters and regulators the copper-nickel alloys have stood the test of time and should be standardized. The use of iron wire should be prohibited as well as any alloy containing zinc. At the present moment many wire manufacturers make the same wire but call it by different trade names. This leads to confusion and is very undesirable. It should be quite possible now to fix upon a series of standard copper-nickel alloys, naming them, for example, British Standard Copper-Nickel Nos. 1, 2, 3, etc., which should cover all usual requirements. Tables of their resistances, temperature coefficients, etc., should be issued.

Motor Starting-gear.

The most urgent matter in connection with starters requiring standardization is that of rating. Closely connected of course with the standardization of rating is the question of the performance of the device under standard test conditions. The requirement of the American National Electric Code is noteworthy in this connection. This reads as follows (N.E. Code 78 *h*):—

> "Starting duty resistances for direct-current motors shall be so constructed that when not more than 10 per cent in excess of the voltage marked on the name-plate is applied to the main-line terminals, and the starting arm is operated at such a rate that the current through the resistance does not fall below the rated full-load current, and this test is continued for not more than three minutes, there shall be no resultant flaming or molten droppings; or if the resistance conductor is fused, the arc or any attendant flame or molten droppings shall be confined within the rheostat."

It would appear that a requirement which allows for the eventual appearance of flames or molten droppings under test conditions is altogether inadequate. A specification of temperature rise and freedom from permanent injury to the device rather should be laid down.

Liquid Starters and Controllers.

Diversity exists at present among the different manufacturers as regards their horse-power minute ratings of this class of apparatus. This would be obviated in future if a standard rating could be fixed. This is only a matter of definition, and could be settled immediately if attention were given to the matter by the competent authority.

Copper Strip Connections of Switchboards.

It would be a great advantage if the cross-sections of strips to be used for making the connections on switchboards were standardized. Hard-drawn copper is sometimes specified for these. Hard-drawn copper, according to E.S.C. Report No. 7, has a specific resistance 2 per cent higher than annealed high-conductivity copper. Its use, moreover, is wasteful as it has to be purchased in straight, comparatively short, lengths. Thus it has to be cut to waste much more than copper purchased in long rolls. Moreover, built-up hard-drawn busbars must contain many more joints which

Sectional Area	Section	
0·039		5/8″×16 S.W.G.
0·064		11/16″ × 3/32″
0·125		1″ × 1/8″
0·188		1½″ × 1/8″
0·25		2″ × 1/8″
0·31		2″ × 5/32″
0·375		3″ × 1/8″
0·5		4″ × 1/8″

Fig. 13.—Suggested standard copper sections for switchboard connections (soft electrolytic copper).

are expensive to make and also the cause of ohmic loss. In view of these facts it would be desirable to standardize on the basis of annealed copper. All strips, except the smallest, should, as far as possible, be of a uniform thickness (say $\frac{1}{8}$ inch) but of varying widths. The use of such thin strips permits of large bars being built up with maximum ventilation; moreover, they are very much easier to handle than thicker strips. The sections illustrated in Fig. 13 are suggested as suitable for the proposed standards.

Temperature rise of connections.—Present-day specifications are very vague on this point. Some engineers specify "no appreciable temperature rise," and other requirements such as "no excessive rise" are common. The measurement of the temperature should be by thermometer. Connections in the immediate neighbourhood of instrument shunts should be allowed to run hotter than the normal, as such shunts dissipate their heat to a great extent through the connections. Temperature measurements should therefore not be required to be made within 1 ft. up such standards. These should form the subject of special specifications to be issued by the Standards Committee. Among the requirements to be covered by such specifications may be enumerated the following:—

Clearances, general arrangement of apparatus and connections, prohibition of the use of inflammable material, passage ways, gates, shields, etc.

From the manufacturing point of view it would also be an excellent thing if the dimensions of slabs used in switchboard construction could be standardized. This has already been done by individual manufacturers and, if all could be brought into line, considerable economy would be effected.

As regards high-tension boards, a code of principles should be set up which would guide central station engineers and manufacturers in selecting the type of board most suitable for the particular service required. This matter is of particular importance in view of proposals for linking-up and bulk supplies, which are likely to be considerably extended in the future. Such linking-up is difficult and costly of realization when

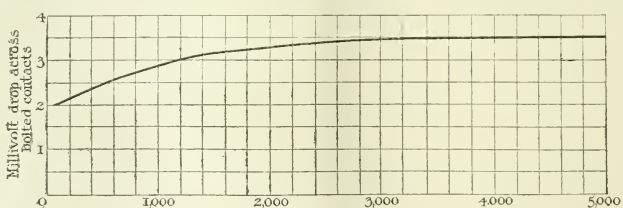


Fig. 14.—Millivolt drop across bolted contacts.

or $1\frac{1}{2}$ ft. of the shunts measured lineally along the conductor. The American Rule No. 722 allows a 30 degree C. rise on cut-outs and current-carrying parts of switches. Large current connections, however, would have to have a higher temperature limit fixed for them than small ones. Reasonable values would be up to 500 amperes not to exceed 20 degrees C. rise; 500 up to 1,500 amperes, 30 degrees C. and 1,500 amperes and above 40 degrees C. A standard of millivolt drop for bolted and riveted connections would be very desirable, and as a contribution to fixing this the curve in Fig. 14 is given showing results obtainable by reasonably good workmanship.

Switchboards.

The only British standards (apart from some minor requirements in the Institution Wiring Rules) as regards switchboard construction which have been as yet established are contained in the official regulations issued by the Home Office and Board of Trade. These latter are, however, concerned primarily with the safety of the workmen and of the public, and while their constructional requirements are excellent in themselves they are not appropriate means for setting the stations to be connected are equipped with differing forms of switchgear.

Cellular or cubicle type of switchboards.—One of the most beneficial principles of high-tension switchgear construction is the cellular principle originally enunciated by Dr. Ferranti. As of late the desirability of this method of construction has been questioned, the opportunity is now taken of raising a discussion on the subject.

In the author's opinion all high-tension boards should be based upon this fundamental idea. Of course the present-day cells or cubicles are very different from the open-fronted pigeon holes originally used. For one thing modern experience has shown that the cells containing the oil switches should be practically gas-tight, or at least only have ventilation or drainage holes from which the emission of conducting fumes or vapours would be harmless. Again, too, the effect of arcs which have been set up as the result of accidents has demonstrated the necessity of very substantial construction of the dividing walls and partitions. There is, undoubtedly, a very considerable amount of practical experience with the use of high-tension switchboards available in the records of the supply authorities in this country. One very beneficial effect of the pre-

paration of the standard specifications suggested would be to render this experience available to the industry generally, with consequent greatly accelerated progress all round.

Reference may be made here to the Commission on High Tension Apparatus set up by the Swiss Elektrotechnischer Verein, and Figs. 15 and 16 are taken from the second report of this Commission.*

The Commission reported that it has been found necessary to leave openings in the oil-switch tanks to prevent their bursting when "internal explosions take place."

Figs. 15 and 16 represent arrangements of cubicles suggested by the Swiss Commission to prevent the oil on issuing from such openings from spreading. These are self-explanatory. In Fig. 16 will also be seen a flap-opening to give relief to internal pressures set up

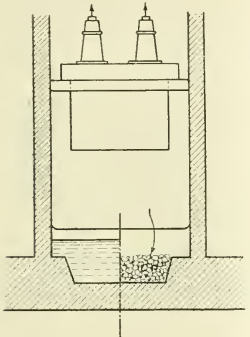


FIG. 15.—Oil well at bottom of oil-switch cubicle partly filled with sand or gravel. The well may be covered with a perforated metal cover.

within the cubicle. The report also recommends the provision of chimneys for the switch cells to carry off smoke, and that cables should leave each air-tight compartment through porcelain stuffing boxes.

It is very much to be doubted whether the cubicle vent proposal shown in Fig. 16 is advisable, but that on the contrary the cell should be as air-tight as possible. It would almost seem that the authors of these proposals contemplate the bursting or blowing-off of the oil-switch tanks as a normal incident of operation. It is very much better to make the switch tank sufficiently strong to withstand, in conjunction with a sufficient air cushion above the oil, any pressure which may be set up due to operating conditions. Such a construction does not offer any insurmountable difficulty. If a vent to relieve pressure inside the oil switch is provided, then this should communicate through a pipe with the open air or to a place where the expelled fumes are harmless. The provision, however, of a drain pipe as shown in Fig. 16 would seem to be a desirable pre-

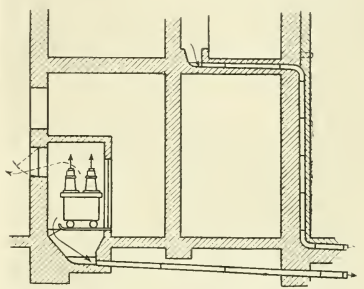


FIG. 16.—Cubicle arranged with drainage pipe to carry off oil expelled from oil-switch.

caution against accidents. One must not, of course, shut out entirely the possibility of accidents, and from this point of view the enclosure of the oil switch within an outer cell which will strictly localize the ill-effects of any such accident is a great advantage.

LIGHTNING PROTECTIVE GEAR.

Horn gaps.—The horn gap forming as it does a necessary constituent of very many forms of lightning arrester should be standardized as regards its shape and jump-over voltage. This latter depends partly upon the diameter of the rod used in the construction of the horns, and this must therefore be specified. As regards material, both galvanized iron and copper yield good results.

Choking coils.—Great diversity exists in present-day practice as regards the size of choking coils used for the protection of machinery against the entrance of dangerous currents. It should be possible, however, to lay down standards (expressed in milli-henries) of inductance which afford reasonable protection in the various cases. If this be done, however, it would be necessary to fix upon a formula which could be generally accepted as sufficiently accurate for the calculation of the inductance of the coils. A mathematically rigid calculation of such coils is a matter of some complexity. Such, however, is not necessary, an accuracy of, say, 5 per cent plus or minus being ample. A general formula with the necessary curves for use under these conditions should not be very difficult to obtain, and their general use would prevent disputes arising.

Reference may be made to the general formula put forward by Coursey for coils of small radial winding depth * and that proposed by Doggett.†

* *Bulletin* of the Schweizerische Elektrotechnischer Verein, 1915, No. 8, and *Electrician*, 1916, vol. 77, p. 8.

* *Electrician*, 1915, vol. 75, p. 841.
† *Electrical Review*, 1914, vol. 74, p. 489.

The precise shape and arrangement of the coil should for the present be left to the different manufacturers. The minimum clear air space between the turns of the coil should, however, be fixed.

Lightning arresters.—There can be little doubt that the future development of overhead electric transmission is bound up in no small degree with the question of efficient protection against lightning. Of late, two methods for the protection of large systems have come to the front, namely, the static condenser system and the electrolytic. The former has been developed on the Continent and the latter, while it was invented in England, has been brought to its present high efficiency in America. It is probable that most new transmission lines of any considerable magnitude in the near future will be protected by the aluminium electrolytic arrester.

A very considerable amount of development work in connection with the aluminium arrester has been carried out in the private research laboratories of manufacturing firms. While a good deal of the results of this work has been, with commendable broad-mindedness, published in the technical Press, naturally much is withheld and regarded as a trade secret. In view of the importance of the matter from the point of view of the future of the British electric supply industry and of the export trade, this is unsatisfactory, as the constants of such a vital piece of apparatus should be common property, just as are, for example, the insulating properties of the commonly used dielectrics.

On page 217 the question of the establishment of a national high-tension research and standardizing laboratory is touched upon. Such a subject as the lightning-arrester problem could be dealt with by such an institution. In this and analogous electrical engineering developments we are not taking the leading place that we should occupy, and if this Institution could, in co-operation with the industry, take steps to alter this it would earn the gratitude of very many of its members.

APPENDIX I

Tests on Oil Switches.

Merriam: *Transactions of the American Institute of Electrical Engineers*, 1911, vol. 30, p. 1195. Tests were made in the Fisk-street station, Chicago, on a 12,000-k.v.a. steam turbine, 9,000 volts, with and without reactances.

Schuchardt and Schweitzer: Ibid., 1911, vol. 30, p. 1143. Deals with the same tests as Merriam. Short-circuit currents equivalent to 71,500 k.v.a. were broken.

Vogelsang: *Elektrotechnische Zeitschrift*, 1913, vol. 34, p. 1. The test consisted of short-circuiting five 3,400-kw. 12,000-volt machines in parallel.

Marguerre: Ibid., 1912, vol. 33, p. 709. Tests were made at 10,300 volts, and short-circuit currents equivalent to 42,400 k.v.a. were broken.

Report of the Commission of the Swiss Electrotechnical Society, Bulletin 1915, No. 8. Tests at 8,000 volts were made, but only small loads were broken.

Stern and Biermanns: *Elektrotechnische Zeitschrift*, 1916, vol. 37, p. 617; and also *Electrician*, 1917, vol. 79, p. 884. Tests made in the A.E.G. special laboratory as described on page 217 at 7,500 volts up to short-circuit loads of 450,000 k.v.a.

J. H. Mahony: *Electric Journal*, 1916, vol. 13, p. 590. Tests were made at 24,500 volts, with short-circuit loads up to 475,000 k.v.a.

APPENDIX II.

Speed of Operation of Oil Circuit-breakers

In order to secure some information as to the actual velocities at which oil switches open circuit, a number

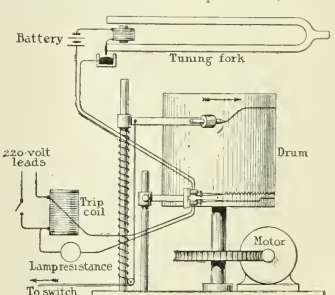


Fig. 17.—Apparatus for determining the speed of break of oil switches.

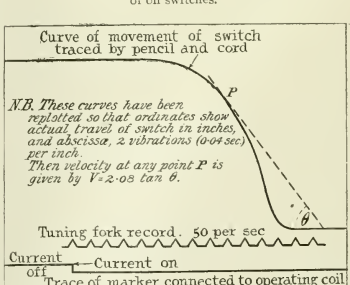

Curve of movement of switch traced by pencil and cord
N.B. These curves have been replotted so that ordinates show actual travel of switch in inches, and abscissæ, 2 vibrations (0·04 sec) per inch.
Then velocity at any point P is given by V=2·08 tan θ.
P
θ
Tuning fork record. 50 per sec
Current
Current on
off
Trace of marker connected to operating coil

Fig. 18.—Explanation of Curves (Figs. 19–23).

of tests were made in the power-houses and substations of a Midland city by kind permission of the chief engineer.

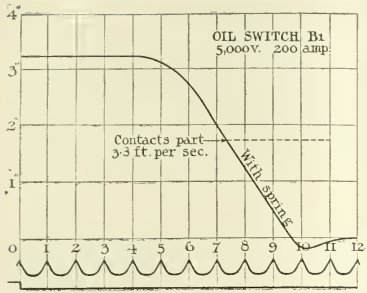


FIG. 19.

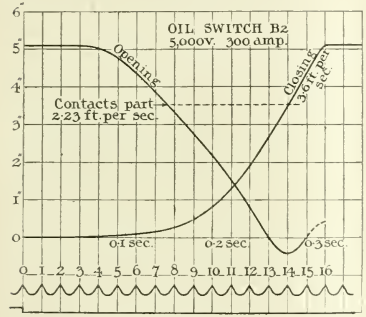


FIG. 20.

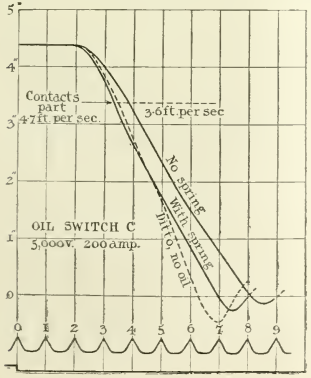


FIG 21.

The apparatus used is shown in Fig. 17. This consists of a rotating drum with a pencil mechanically connected to the moving portion of the switch. At the bottom of the drum two traces are made, one by a tuning fork vibrating at 50 times per second and the other by a marker connected across the trip coil. The latter thus shows exactly when the tripping circuit is made, and the tuning fork gives a time scale.

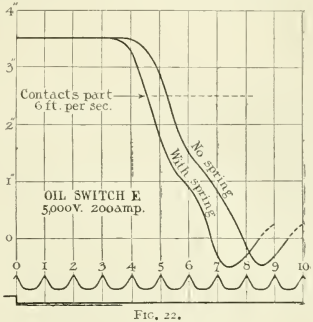


FIG. 22.

Fig. 18 gives a representative result.

Fig. 19 is a record of a 200-ampere 5,000-volt switch. This has had an extra spring inserted in the mechanism to accelerate the break. It will be seen that the contacts separate at a speed of 3·3 feet per second. It will also

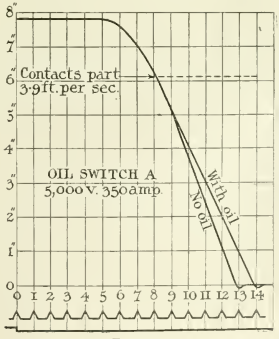


FIG. 23

be remarked that once this speed has been attained, which takes place after about the first inch of travel, it remains constant during the rest of the movement.

Fig. 20 is the opening and closing record of a solenoid-operated oil switch. The rupturing speed is 2·23 feet

per second. On closing, the time taken before the contacts touch is 0·28 second, which is a good result.

Fig. 21 is the record of a switch having a brush contact, and shows that the effect of the oil on the speed is very little.

Fig. 22 brings out particularly the effect of the added accelerating spring in the transmission mechanism. It will be noticed that although the addition of the spring resulted in the time of opening being slightly shorter, it made no appreciable difference to the speed of break.

Fig. 23 shows again the little effect of the oil. All these tests were taken on the switchboards of the power-houses mentioned.

From the results, a good idea can be obtained as to what speeds may be expected in oil circuit-breakers supplied by the various manufacturers at the present day. With the exception of Fig. 19 and Fig. 20, which relate to apparatus by the same maker, they are all products of different firms.

The author has to thank Mr. W. Wilson, B.Sc., who carried out these tests for him.

Discussion before The Institution, 21 February, 1918.

The President: There are one or two points that I feel it necessary to remark upon before the discussion is opened, and one in particular, namely, standardization. I am glad to see the author recognizes that the authority for engineering standardization in this country is the Engineering Standards Committee. That is a fact which I think every section of the electrical industry should abide by loyally; and the industry should give its utmost support to that body. The question of high-pressure switchgear has already been very seriously considered by the Committee. Last November Mr. Hobart was in this country, representing the American Engineering Standards Committee, and the members of the British Engineering Standards Committee and the B.E.A.M.A. had a very full conference with him on this subject of high-pressure switchgear and its standardization; it was agreed at that conference that the matter should be taken up actively and that we should co-operate with the Americans in the matter, in the same way as we had co-operated with them in regard to the rating of electrical machinery. The Engineering Standards Committee is in all cases in active co-operation with the B.E.A.M.A. in this matter, and there is about to be set up a strong Sub-Committee of the Electrical Sectional Committee to deal with this very subject as the author advocates. The intention was formed last November, but for various reasons the Sub-Committee has been some little time in getting together, one reason being that the constitution of the Standards Committee is under reconstruction. Again, it is necessary to co-operate with the B.E.A.M.A., as I have already said, and the preliminaries have to be arranged. But there is every prospect that the work will be taken in hand in the immediate future and pressed forward actively. In connection with motor starters, a Panel is already in existence which has been very hard at work and has already produced, and has nearly ready for publication, a Standard Specification for one particular kind, that most widely used, namely, the face-plate rheostatic type of starter. Thus, although there may not have been very much published, the Engineering Standards Committee has been active and is contemplating very great activity in this matter in the near future. Then again I should like to say one word in connection with the proposed national body for investigating high-pressure phenomena. I am entirely in agreement with the author in the pressing need for full investigation of many matters in connection with the electrical industry, but I do think it is important as far as possible to use existing institutions and develop them, rather than set up new ones. I am extremely hopeful that we shall shortly have a great development of activity in connection with all the Local Sections of this Institution. The Birmingham Local Section is extremely eager to take part in this work, and the Newcastle Section is also particularly interested in switchgear, and is very anxious to take an active part in the matter, being well equipped for it. I hope, therefore, that the Standards Committee, which will unquestionably require a good deal of help in the direction of research in connection with this and other matters, will be able to call upon the Institution for very active assistance, and that the Institution will be able to utilize its Local Sections effectively in the direction of sub-dividing the research and letting particular Local Sections form Sub-Committees, not necessarily composed exclusively of members of such Sections, to take up the different branches of research, so that as a whole a very great deal of work may be accomplished in a relatively short time. The work may then be handed on to the Standards Committee for utilization in the Standard Specifications. Standardization is one of the most thorny subjects which it is possible to undertake. It is not merely a question of investigating the best standards to be set up, but much more largely a question of reconciling conflicting interests, and getting agreement amongst those who have particular patterns and types to exploit, which very often are extremely good. It is necessary to get them to come to a general agreement as to standardization, without which agreement it is hopeless to put forward proposals, however good in themselves they may be. It is not enough that the standards put forward should be good ones or practical ones from the users' point of view; it is essential that they should be standards which are acceptable to the manufacturing interests of the country.

Captain A. M. Taylor: I wish to look at the question from the point of view of the operating engineer, and also, incidentally, from the point of view of the inventor. I hope that if, and when, any Committee is set up for the purpose of standardization, care will be taken to secure the advice of the operating engineers. As regards the switchgear for extra-high-tension work and for very large powers, the operating

engineer's experience is, and should be, of the greatest value. Any Committee consisting merely of distinguished men, whether scientific or commercial, may be led to form conclusions doing a grave injustice to a particular class of apparatus. If they allow their desires for standardization to lead them to approve of, say, only one class of oil switch for all services, they may be quenching the invention of a switch which may open up new possibilities in the way of handling large, or small, powers successfully. Let it be granted that (1) there must be special types of switches for special purposes, (2) there must be special types of switches for the breaking of large powers, and (3) there must be every possible opening left for inventive talent; then, as far as oil switches are concerned, I should feel more ready for standardization. The author himself seems to have fallen a victim, to a small degree, to the standardization craze, for he hints at doing away with two-step switches. I believe such switches will find a field of their own in those cases where there is trouble from excitation currents at the closing of the switch, as, for instance, in the case of a high-tension line where the current was stepped up and then down again and where switchgear was only employed on the low-tension side; or, again, in the case of static frequency-changers. Take the case, for instance, of the method of opening the break. I hope that some one having no actual experience of the behaviour of oil switches on a large scale will not say: "Why do we want two different types of switch? Let us merge the horizontal-under-crossarm break into the vertical circular-oil-pot break and have only one type." I believe that would be the greatest possible mistake. Then, with regard to inventors. If standardization is made too much of a fetish, the inventor will be at once met with the reproach that his switch would involve new tools and patterns and would cost too much. As the author remarks, it is very difficult to get new types of switches tested under great powers. Central station engineers fight very shy of any experiments that might cause trouble. I could testify that such is the case. Even in standardizing *performances* there is a difficulty. For instance, the author gives a curve (Fig. 8) which, though it may possibly represent experimentally the results obtained with a particular switch—perhaps with a horizontal-under-crossarm break (as in Fig. 6)—would give totally wrong results for, say, a switch like that of the General Electric of America, because, for one thing, the head of oil is not specified, and also the oil that is used is not employed to the best effect. The rating of oil switches is one of the most misleading things I know of. One maker will state that his switch will break, a certain number of times in succession, the current represented by so many kilowatts connected to the busbars. Another maker will claim that his switch, which we can see is not such a good one, will break twice that kilowatt capacity. When we come to investigate, we find that the second man has traded upon the time-lag of apparatus and the wiping out of the generator field, so that the number of kilowatts which his switch actually interrupts is perhaps only half those interrupted by the first switch. A standardized clause clearly drawn up by operating engineers of large experience might be really useful here. The author hints, on page 224, that there are different opinions about the value of cellular switchgear. I have no hesitation in expressing my preference for the open type of busbars and connections, isolating switches, etc., always provided that insulators are so substantial that they cannot possibly shear, isolating switches so rigidly locked that they cannot possibly be blown open, connections between busbars and switches so rigid that they cannot possibly be bent by the current, and flame-tightness (and also explosion-proof) between cell and cell is above suspicion. We can at least see, and test, by means of a little paraffin on the end of a long stick, even when current is on, whether every part of the system is doing its duty. With reference to the clause at the top of the second column on page 219, I quite concur in the author's remarks regarding speed of breaking circuit, and with the greater satisfaction because when, about 6 years ago, I was strongly advocating the same course, there were not wanting, in high quarters, those who opposed my conclusions—both here and in the United States. It was put forth that any increase in the speed of break was only attained at the expense of a greater (induced) electromotive force across the break, which therefore modified the gain due to the greater rapidity of breaking. With regard to the non-inductive resistance shown at (A) in Fig. 6, this does not seem to be a very happy arrangement, since it must add considerably to the inertia of the moving parts, which should be kept down to the absolute minimum. With regard to the form of break shown in Fig. 6, I have known cases where the central insulators (left-hand diagram) sheared horizontally, apparently because of unequal thrust—combined with side thrust—on the two ends of the bridge piece. Most makers employ porcelain insulators; these do not stand up to the "hammer blow" of the magnetic repulsive action of the current, which I have proved, from effects on the main busbar insulators, to be far more serious than would be gathered from a calculation of the forces brought into play by the current. The breaking effect on the porcelain must therefore be purely a matter of the suddenness of the establishment of the magnetic force. For these—and other—reasons, I rather doubt the advisability of having anything but a straight-line break where very large currents have to be considered.

Mr. E. W. Cowan: I find it rather difficult to criticize this paper because I am so completely in agreement with what the author has said. The author refers to the specification for brass and gunmetal castings, and I think it would be an advantage if another alloy were included, a high-conductivity cast metal. We all know that gunmetal has a very high specific resistance, and that brass also has a high resistance, but an alloy which is used a good deal and is sometimes called red metal, composed of copper, zinc, and lead in different proportions, ought I think to be standardized. I am using an alloy of this kind which has a specific resistance 28½ per cent that of gunmetal and 43 per cent that of brass, but it has an inferior mechanical strength. It follows that when we improve the conductivity of cast metals we get less mechanical strength. This red metal alloy possesses the electrical

qualities of cast copper without the great objections that there are to the use of cast copper both from a foundry and from a workshop point of view. The knife switch shown in Fig. 1 I like very much. The only suggestion I would make with regard to it is that I think it would be a better switch if there were more points of contact than one on each side; that can be easily obtained by making a multiple contact generally similar in design. I have always been very much alive to the fact that we think too much of the area of contact and too little of the efficiency of the points of contact. One cannot get the whole area in contact, and when one remembers that a point of contact has no length it will be realized that its conductivity may be very high. As a matter of fact the resistance is not, I think, at the point of contact but where the current from the point of contact spreads out into the body of the metal. If we multiply the number of contacts we get better results. I very much approve of the author's millivolt methods of standardizing the conductivity of contacts, and I think the millivoltmeter ought to be used more in central stations and in all electrical work. One can in a short time test hundreds of joints and record the millivolt drop across them. In one case in Manchester where I was installing some 5,000-ampere switchgear, there was at first heating of an alarming kind, but by going over the circuits with a millivoltmeter and discovering where the origin of the heat was, I was able, with the help of a fitter, in a comparatively short time to bring the conductivity up to what was required. In another case I had an oil switch back from the users, who said that it heated badly. I made a test of it as it was, taking the millivolt drop across the contacts. I then opened the switch and wiped the contacts with a petrol-soaked rag, with the result that the conductivity of the contacts was increased 300 per cent by that simple operation. The trouble was oxidation of the contact surfaces. One must be careful to have the contacts clean before they are immersed in the oil, and then they will remain electrically clean. Coming to the oil-switch question. Captain Taylor has already said, and I agree, that to specify the quantity of oil is not satisfactory; it is the head of oil which should be taken into account. I had the opportunity in October 1914 of visiting Johannesburg and having a long talk with Mr. Price about his oil switches, and he told me he thought he had had in Johannesburg more severe conditions than obtained in any other part of the world. The way he had got over his difficulties was very interesting. He said that practically all the trouble with the oil switches was due to a vapour rising to the surface in a high state of incandescence and getting in contact with combustible gas, an explosion then following with disastrous consequences. He hoped that he had solved the difficulty by placing the contacts in what he called explosive pots—the contact being practically enclosed in a diving-bell shaped container with an opening at the bottom for the switch tongue to enter and reach the contact. Thus by forcing any escaping incandescent vapour to follow a tortuous path through the oil, the cooling and consequent quenching effect was increased. The type of switch he favoured most was one with a big head of oil above the top of the contacts. In conclusion I may say that I am enthusiastically in favour of the real objective of this paper. More standardization is wanted, and competition between manufacturers will not give it. Standardization is of benefit to the industry and to the consumers. The industry should carry out its own standardization and benefit will accrue to all concerned.

Mr. C. Baker: As far as standardization goes, we are doing a good deal, and successfully. I feel it is the manufacturers who must do the work, as they are the only ones who can bring it to a successful issue. We do not manufacture oil switches, but I have standardized on one make. It should be an easy matter to settle the break, centres of contacts, and centres of poles for knife switches. The same figures would be useful for laminated brush-type switches and automatic circuit-breakers. With regard to the table on page 215 of the paper, I suggest that $\frac{1}{4}$ inch be the smallest size stud used for terminals, and $\frac{3}{8}$ inch for knife switches; also that Whitworth threads be used up to $\frac{1}{2}$ inch diameter—above that size the standard for electrical conduit threads be used. The thickness of nuts in Table 2 should be increased considerably; a spring washer is advisable under all nuts used for connections. I suggest that clamp sockets on plain stems be also standardized. The list of copper connections given is interesting. I suggest $\frac{3}{4}$ inch $\times \frac{1}{8}$ inch instead of 11/16 inch $\times$ 3/32 inch; also that 2 inch $\times$ 5/32 inch be omitted. It would indeed be a great help to the industry if the Engineering Standards Committee were to issue a specification dealing with switchboards on the lines suggested by the author. Details of the tests required should be included in such a specification.

Mr. H. H. Berry: I find myself in agreement on the technical points with almost all the items in the paper, and in many of them, as a matter of fact, the results have been arrived at in direct collaboration with the author. There are, however, one or two rather important points that I should like to say on the purely administrative effect of this paper. The two primary points that have been given us for consideration are the question of standardization and the question of setting up something of the nature of an electrical proving house, to prove the apparatus that we have actually standardized. I want to direct the attention of members to what has been done on the other side of the Atlantic. I have spent a great deal of time in studying the methods of the particular body to which the author refers, that body which provides us with the National Electrical Code of America. When I was in Chicago several years ago all the apparatus by which the tests referred to in the paper were conducted, and others, were kindly placed at my disposal for inspection, and I was able to witness some of the tests in the particular laboratory established by the National Board of Underwriters. The point I particularly want to make is this. In our efforts at standardization, do not let us make it the fetish which it has become in the United States. I say this perhaps against my own interests as a British manufacturer, but I feel that the point is a national one. In the efforts to standardize in the United States they have, in my opinion, gone the wrong way to work from the manufacturers' point

of view. They have a body there, the Underwriters, who have set up a laboratory, and the Committee of that body is composed largely of those who make the articles which have to be tested, and it seems to me a necessary corollary that the particular body derives its source of income from the manufacturers whose standard apparatus has to be tested. The evil of that system when applied without correction is that apparatus has become standardized in America to the elimination of simpler apparatus that might very effectively perform the same purpose. The distinction that those of us who are concerned with Standardization Committees in this country are endeavouring to make, is to standardize the very simplest and most effective form of apparatus, having particular regard, as the President has already said, to those specialists who have devoted their lives to developing some particular form of apparatus which may be very ingenious but which can never be interchangeable. In America in my opinion they have placed a direct embargo upon inventive talent, by saying not only that they will have a standard because it is fairly good, but that they will not allow anything that is better, because it is not interchangeable; and, by reason of the administrative body giving effect to that decision, it is a fact that apparatus which will scientifically perform an operation more correctly and cleverly than the standard apparatus is disregarded because it is not interchangeable, and it is thrown out purely on its demerits of non-interchangeability. I saw with very great regret in the electrical Press quite recently a note to the effect that this country was suffering by its pre-war foolproof madness, and I was very glad to see in a subsequent issue a small editorial in which the editor accepted the responsibility of saying that he did not personally subscribe to that policy and acknowledged the merits of the high-tension apparatus which has been developed in this country with foolproof characteristics. In my opinion it would be extremely wrong of us to attempt to standardize on too low a grade if standardization meant taking off the market the apparatus for which there is a demand. Incidentally I want to say that in the editorial note or comment the point was made that we had suffered in pre-war times because we found that we could not compete with the United States of America. The man who wrote that note was really incorrect in his facts. The particular motto at the moment in the United States that seems to come before everything is "Safety First." They have suffered so much loss of life due to electrical accidents and accidents at railway crossings that they have learnt to be careful. I think the statistics for America show 25 times the loss of life by accident that occurs in this country, and therefore they have made every effort towards safety, and a particular Department has been established at Washington to create a demand for "Safety First," and they will now probably go to the other extreme and follow in the wake of our experts who led the way.

Mr. E. T. Williams: I should like to emphasize one thing. The first high-tension switch I ever used abroad was an example of what ought to be avoided. From the minute it was put into use until it was finally discarded it was a source of continual worry. That switch before it was sent out had been examined and passed by inspectors of repute in England. I do not think the manufacturers realize the much greater difficulties that engineers have abroad than in England when gear gives trouble, and I do feel that it is better to lose orders from abroad than to send something out which will be a cause of trouble. I have seen the results of standardization in other countries, and I am convinced that if we want to compete we must take up this question of standardization in a thoroughly hearty and unanimous way; and if manufacturers are going to let vested interests stop the good work of those engaged on standardization, I think they will be standing very largely in the way of their own interests. I take it that the primary intention of standardization is not so much ease in replacement as to avoid making a multiplicity of patterns where fewer patterns will do, and thus get a better article at a cheaper price. If, as Mr. Berry said, standardization is so ordered that it is going to cut out ingenuity and invention, then I think that that tendency will have to be very closely checked. We must standardize to get a good article cheaply by avoiding a multiplicity of patterns, but also we should be in the forefront in welcoming new inventions and new applications. The author in referring to lightning arresters mentions two types, and says that the former has been developed on the Continent and the latter, while it was invented in England, has been brought to its present high efficiency in America. I know that the feeling abroad is that if one wants anything of a special nature taken up one should go to America and before the War to the Germans also. Whether that is right or wrong, there is no doubt a very strong feeling that British engineers have not been the people to go to to get anything taken up that is a little out of the ordinary, and while we are standardizing—no one is stronger than I am for it—let us by all means welcome and give every consideration to any ideas that may be put before us.

Mr. A. E. Gott: I think we are all agreed that standardization is very necessary, but we want a very clear definition of the term. The author has attempted to define it, but I do not think he goes far enough. Standardization should include in its definition the use of standard sizes and compositions of material and standard tools and processes for production. My reason for referring to a definition is that in the B.A. screws we have an example of standardization which is rather deplorable, not because they are metrical but because, owing to their fractional dimensions, they almost defy the origination of tools. Reference is made in the paper to standard test-pressures, but there is no reference to induction in the circuit, which I regard as extremely important. Given sufficient induction one never knows what may happen on interrupting a circuit, and I have recollections of surprising effects in opening inductive circuits. I do not attach much importance to the specifications for brass as they are mechanical rather than electrical. In considering conductivity, some notes from the almost forgotten Hospitalier's pocket-book (about 30 years old) are interesting. It is stated that the introduction into copper of a trace of arsenic will lower the conductivity to approximately

60 per cent, and less than 3 per cent will lower it to 15 per cent; a trace of zinc will lower the conductivity to 88 per cent, and 3 per cent will lower it to 60 per cent. Of course when one is dealing with large currents conductivity is important, and for copper castings necessitates clean new pots, electrolytic copy, and either no flux or only those which have no lowering effect. I have known workmen to flux electrolytic copper secretly with arsenic and lower the conductivity to 30 per cent. In making castings, a $\frac{1}{2}$-in. diameter bar 18 inches long cast in forms a convenient test-bar for conductivity. Current is passed through it at 3,000 amperes density and the millivolts measured between two points approximately 15 inches apart (14·7 inches). The current density divided by the millivolt drop gives the conductivity from 20 per cent upwards in any instrument reading up to 150 millivolts with sufficient accuracy for any practical purpose, and corrections for finer accuracy may be applied by weighing against a rolled bar if necessary. Referring to knife switches, satisfactory operation of contact is entirely a matter of the relation of current to the amount and surface of metal. Fifteen years ago I introduced the millivolt method of testing switches into the workshop, with eminently satisfactory results, and a switch properly scraped, irrespective of its current, would give something of the order of 5 to 10 millivolts across the contact. In the case of large switches, however, a satisfactory design is by no means simple, and there is certainly something to be said in favour of clamping the jaws after the contact is made. Nothing is stated in the paper about soldered connections. After a disastrous switchboard experience in which soldered connections melted, means were adopted for testing these connections immediately the workmen had made them, and it is interesting to know that a really good soldered connection will not give more than one or two millivolts' drop, whereas one badly made, but which has a good appearance so far as workmanship is concerned, may give as much as 50 millivolts. That method eliminated bad work, and it was found that the workmen became equally interested in the results. In the sizes of switch bolts suggested I notice that the pitch is 11 threads to the inch, this being the standard pitch for iron-pipe threads, in which the nominal sizes are the inside pipe measurement. I do not think these threads suitable, and as an alternative I would suggest that "fine steel conduit threads" be considered. There are also too many sizes in the table, and the smallest sizes are too small for mechanical reasons. There should be a minimum size in switch bolts comparable with the mechanical engineer's minimum sizes in shafting for manual operation.

Professor J. T. MacGregor-Morris: I agree fully with other speakers that standardization is most desirable, but it must be done in a broad-minded and far-seeing way so that it does not limit ingenuity and invention. With regard to the conductivity of current-carrying alloys, the last speaker has mentioned the variations in resistance owing to slight admixtures of other materials. From some considerable experience in this matter, I would say that there are certain alloys which are well worth looking into with regard to their mechanical and electrical properties—alloys which might take the place in switchgear of the materials which are used at the present time. Aluminium cannot be got during the war, but we have to deal with things which will be of use after the war as well, and I suggest that rolled aluminium and other materials closely allied to it should be included. With regard to the question of contacts, I am sure that Mr. Cowan made an important point when he alluded to the fact that too much attention is paid to the area of the contact instead of to the efficiency of the contacts. Anyone who has worked at trying to improve the contacts of a switch must have been impressed with the fact that it is far more important to have a small contact which is efficient than a large area ineffectively used. I want to make a suggestion with regard to oil switches. The interruption of an arc is done most effectively immediately the arc starts; would it not be worth while therefore to make tests on switches with perforated faces? Suppose we have two contacts which have a number of perforations and the oil is forced into the space in a series of jets when the contacts separate; the arc might then be extinguished before it attained any serious length. With regard to fuses, I do not think it is fully realized that the time required to break a circuit on sudden short-circuit varies with different materials. It can be easily written down as an equation. If we have a copper fuse and a tin fuse in series with one another and so chosen that they will melt at the same steady current, then on a heavy short-circuit the copper fuse will invariably clear the circuit leaving the tin fuse intact. That effect enables us to grade fuses in series with one another so that with perfect definiteness one particular fuse will invariably clear the circuit, though all the fuses are of the same steady rating.

Mr. A. H. Ellis: As a user of apparatus more than a designer, I should like to make a few remarks from the point of view of one responsible for the electrical side of a large supply undertaking in London. The author advocates combined action on the part of designers and manufacturers, and I think it would be of advantage to add also users. With regard to knife switches, I agree there should be some standardization, but on somewhat mechanical lines. It is very awkward to have a 10,000-kw. turbine depending on a little switch with paltry contacts, failure of which would jeopardize the whole of the supply. The contacts and blades should be more robust than is required electrically, so that when a man cleans them he will not pull them apart or bend them and put them together again with his fingers or a pair of pliers. To check the millivolt drop in switches may be all very well in a manufacturer's shop, but would be quite out of place in a large undertaking with hundreds of contacts. With reference to the studs of switches, I suggest that no studs should be less than $\frac{3}{8}$ inch in diameter for mechanical reasons. With regard to nuts for connections, I would recommend that the area of thread in the nut should be equal to the surface, and the nuts should be large enough to take a standard Whitworth spanner. On the subject of oil switches, as one who has carried out a number of short-circuit tests on a very large oil circuit-breaker,

I might mention one or two things which may be useful in standardization. The author appears to think that the blowing up of a switch tank is a very rare occurrence, but it is a very common occurrence with high powers. I have known several tanks to have been blown off in the space of a few months. The tanks should be constructed of boiler plate or high-tensile steel and sufficiently supported by strong holding bolts to keep them from being blown off. The oil should be pure, with no traces of moisture, which has a great effect on the rupturing capacity of the switch. Regarding the maximum possible breaking capacity of an oil switch, that is a thing which we have tried to get to the bottom of in this country and in America, and it is not satisfactorily solved yet. It depends on so many things, such as power factor, etc., and other constants of the circuit, besides the form of switch break and speed of opening. Tests made with a multiple-break switch seem to indicate a greater breaking capacity than with the same switch speeded up. With reference to two-step oil switches, I believe the reactance type has been used in the United States with satisfactory results. I cannot quite agree with the author's curve in connection with the length of break in oil switches. I do not think we have any switch where the length of break for 10,000 volts is as he gives it there. The minimum is about 12 inches and goes up to 40 inches. The length of break is, however, not necessarily a function of the rupturing capacity of the switch. There is a danger, as previous speakers have pointed out, of having too much oil. I do not think a great volume of oil is necessary, provided there is a good head of oil. On a certain type of switch which we have in use in the station, with a 9-inch head, or three gallons total, of oil in the switch, we have broken as many as 50 short-circuits in one day on the high-tension side with satisfactory results, each short-circuit being of 60,000 k.v.a. Another type of switch with scarcely any head of oil over the arc-break contacts, but with about 20 gallons in its tank, was blown to pieces on the first short-circuit. As to cut-outs, I have had experience of testing hundreds of these on dead short-circuits across generators. I will simply mention 500-volt cut-outs. After having had serious trouble due to fuses failing in motor starters, it was decided to send out inquiries to various manufacturers for an enclosed fuse which would break the circuit without any damage to the surrounding gear. We had about 40 different types of fuses, and they were simply connected straight across a 400-kw. 500-volt generator. The result was not satisfactory; the test gear was nearly wrecked every time the switch was closed. We persevered, however, and at last got a test on a particular type of fuse from 25 amperes up to 100-ampere rating. Something of that nature I think necessarily must be done to test the fuse under the most severe conditions that can possibly be met with in the station. I think the vents shown in the diagram on page 225 for the oil switches are a decided advantage. Unless that vent is provided there is no escape for gas suddenly formed, with the result that something has to suffer unless the tank and cellwork are made enormously strong to withstand the pressure. Mr. G. W. Partridge advised the use of the vent long before, I think, the Swiss Standardization Committee mentioned it, because we found it was necessary.

Mr. W. T. Tallent-Bateman: I quite agree with the author that it is desirable that standardization work should be encouraged to the highest degree possible by manufacturers and users, wherever standardization principles are applicable. Such a course is desirable both from a national as from a particular manufacturer's or user's point of view. I further agree with the author that at first sight switchgear does not seem a very fit subject for standardizing; on closer consideration, too, at the moment, I hardly think switchgear offers an opportunity for general standardization. Standardization has a very definite object which must on no account be overstepped, that object being to produce materials, articles, or apparatus in as economical and rapid a manner as possible, so as to bring into the country, and at the same time to the manufacturer or user, the very maximum return for expenditure involved. With such an object I do not consider that general similarity or uniformity of design would produce a useful result where large switchgear is concerned. The case is not a parallel with such articles as plugs, ceiling roses, ship's cut-outs, bolts and nuts, etc., where the articles may be used in enormous numbers and made by different firms to work in connection with the multifarious productions of other firms. Large switchgear is used in comparatively small numbers and interchangeability is not so vital a necessity, neither should there be need for frequent replacement. Uniformity of design would not assist in production, as different manufacturers would still need to have their own tools, jigs, patterns, drawings, etc., also a staff to deal with the work. The author confesses on page 216 that the action of heavy-duty oil switches is very little understood, also that oil-switch ratings given by certain manufacturers may only be intelligent guesses. If he is correct, a definite reason is at once shown why standardization at the moment is undesirable. Premature standardization actually tends to breed a stagnation of ideas and may bolster up designs which later on may be found to be highly undesirable; further, it diverts the sense of responsibility from the manufacturer or user to a third party who is unable to discharge such a responsibility. Such a state of affairs has actually occurred in the case of the V.D.E. rules, which are not so much the outcome of carefully worked out standards as a tabulation of the data of existing designs of certain Continental manufacturers. They do not take into account many first principles of oil-switch design—for example, speed of break, mechanical strength of oil tanks, etc.—while bringing into undue prominence certain dimensions which are not necessarily of first importance. The V.D.E. rules have undoubtedly hindered advancement in connection with oil circuit-breakers and have taken from the manufacturer and user any responsibility he is usually expected to hold, resulting in apparatus incapable of withstanding the heavy duty often required of it being installed. Before standardization can be completely adopted, a thorough exploration of all requirements is needed, also a complete investigation into the technical considerations involved and the best

way of meeting them, after which a thorough test with the application of various shop methods and materials to be employed in the manufacture and supply. To my mind a right idea of standardization encourages individual effort and research and does not necessarily imply a general pooling of privately obtained information and data for the use of any twelfth-hour competitor. Such a course would amount to something approximating a confiscation of proprietary interests such as are encouraged by the patent laws, and which could only be effected by a nationalization of the industry. I believe that the principle outlined on page 216, viz. that "the buyer therefore in choosing which switch to purchase is greatly influenced by the opinion he holds of the technical knowledge of the manufacturer offering the goods," is perfectly right and in accordance with all trading mentality. I think that such matters as temperature rises, test pressures, composition of alloys, stud diameters, threads, nuts, copper strip or tube sections, definitions, etc., can with great advantage be standardized, and I am glad that the Engineering Standards Committee are actively engaged in such work. With regard to the author's curves relating to millivolt drop, Figs. 2, 9, and 14, I contend that the important point to standardize is not the millivolt drop but the temperature rise, as this takes into account the total watts lost, the total cooling surface, and the emissivity. Obviously the millivolt drop depends entirely on the total mechanical pressure applied at the contacts, also upon the current passing through the particular material used; the curves are not therefore very illuminating, as no mechanical pressures are given in the various cases. So long as a total mechanical pressure is applied, the form of contact (flat, line, or point), within certain limits, does not materially affect the result. The temperature rise is the important matter, of which the millivolt drop is only a factor; a millivolt drop may, however, be a very useful means of comparison in a manufacturer's works after the constants of any particular design have been obtained. I do not see much necessity for limiting a switch of the type shown in Fig. 3 to currents from 3,000 amperes upwards; it might be found convenient to use such a design for lower currents. In connection with high-tension research, this work could very conveniently be carried out by one of the existing laboratories or a Government laboratory, but such matters as breaking capacity of oil circuit-breakers, which now only need investigation with very large plants of, say, 100,000 kw. or over, could only be dealt with by large supply authorities who already have the necessary plant, cable networks, etc., necessary for the test. State assistance might possibly be obtained to ensure that tests on such a large scale might be carried out at reasonable intervals. Dealing with breaking capacities, it is very necessary to be quite clear what is meant when asking for, or giving, such information, as many expressions might be used, each of which might prove very misleading. The values are usually expressed in kilovolt-amperes. First, there is the actual value representing the total capacity summation of all generating plant (synchronous machines) connected to the system, expressed in kilowatts or kilovolt-amperes; for distinction from other values this might be termed "the aggregate generator capacity." Secondly, there is the virtual value, which is proportional to the particular value of amperes occurring at short-circuit and the normal voltage of the system; this value might conveniently be termed "the switch short-circuit

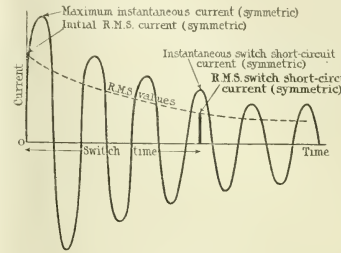


FIG. A.—Symmetric short-circuit.

capacity." It is important to select, in using the second term, the correct value of amperes, as any of the values shown in Figs. A and B might be taken with highly misleading results. It should be borne in mind that it would be a very difficult matter indeed to open the switch at the exact instant of short-circuit, and a short

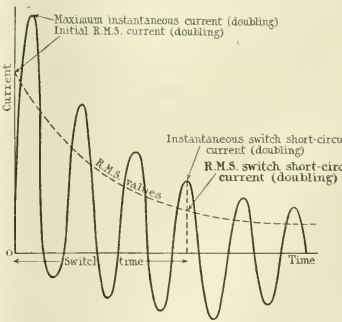


FIG. B.—Non-symmetric short-circuit, showing doubling effect.

period usually intervenes, by which time the current may have assumed a different value. The values to consider, apart from the constants of the switch, are obviously the current occurring while the arc is taking place within the oil tank and the voltage occurring immediately afterwards (both values of course being R.M.S. values). As the "doubling" effect may often

have very nearly ceased to exist by the time the switch opens, the current value might be assumed to be that due to a symmetric short-circuit. The correct ampere value to be selected is shown in Fig. A by the heavy line. The author is not quite clear in his remarks on page 217 under the heading "resistance and reactance oil circuit-breakers," as he seems to refer to two varieties of switch, viz. (1) the switch for opening short-circuits in successive steps obtained by means of limiting resistances or reactances, (2) the switch for limiting simply a rush of magnetizing current when switching on a motor or transformer. One cannot say until the limit of rupture capacity of a simple oil switch has been found, whether it may or may not be necessary to adopt such a principle as (1), of course bearing in mind the use of busbar sectioning reactances and generator reactances, etc. With (2) it should be noted that to be really effectual the resistance should possess, for the varying conditions of service, heavy proportions and great mechanical strength, which could not conveniently be accommodated inside an ordinary oil-switch tank; resistances such as these should be discouraged, except in those few cases where they are really necessary, and then they should be mounted outside the switch as a separate piece of apparatus. The curves shown in Figs. 7 and 8 have not very much practical value, as the total break per phase is dependent not only upon voltage but upon the short-circuit capacity and form of switch—it is well known for instance that a switch plunging downwards (away from the gaseous formation) requires less total break than one moving upwards through the oil, thereby following the gaseous formation. In the latter curve the breaking capacity can hardly be considered to be dependent upon the number of gallons of oil. The values obtained from these curves are factors only in the problem and are dependent therefore upon each other only in so far as the horse-power of different sizes of engines may be said to be determinable from a knowledge of the steam pressures. In connection with the time element of a fuse, I consider that in the vast majority of cases in practice the fuse is regarded as a cheaper substitute for a circuit-breaker and is only approximate in its requirements. It is subject to many variables which make it very difficult to produce and maintain a fine degree of accuracy. Time spent in producing such unnecessary degrees of accuracy might well be used to better purpose, and I suggest that after the manufacturers' private investigations have been completed, there is no more need for extreme closeness of accuracy in time values; these, after all, follow natural laws and might be left to take care of themselves. Exception might, however, be made in special cases, for instance in the case of fuses as used for obtaining "inverse" time delays for circuit-breakers or similar work.

Mr. C. le Maistre: I am afraid I do not entirely agree with the last speaker's views on standardization. It is extremely difficult to define what we mean exactly by standardization, but one gets a broad view of its underlying principles by listening carefully to the various discussions on the subject. I was very interested in Mr. Berry's remarks with regard to the Chicago Underwriters. I think they are not supported solely by the manufacturers; they are very largely supported by the insurance companies and others. Since Mr. Berry was in America there has been a reorganization of their system, and it is probably now on very much broader lines than it used to be.

Mr. F. Gill (*communicated*): The practical meaning of standardization seems to be very inadequately understood, and it is disappointing at this date to have opinions expressed that standardization involves lack of progress. Those who, like the author, have been accustomed to the word "standard" in dealing with such matters as standard equipment, standard practice, standard performance, have no difficulty, but others appear not to be so clear as to what is intended. Perhaps the definition given by M. L. Cooke * may help in this matter:—"A standard under modern scientific management is simply a carefully-thought-out method of performing a function, or carefully-drawn specifications covering an implement or some article of stores or of product. The idea of perfection is not involved in standardization. The standard method of doing anything is simply the best method that can be devised at the time the standard is drawn. Standard specifications for materials simply cover all the points of possible variations which it is possible to cover at the time the specifications are drawn. Improvements in standards are wanted and adopted whenever and wherever they are found. There is absolutely nothing in standardization to preclude innovation. But to protect standards from changes which are not in the direction of improvement certain safeguards are erected. These safeguards protect standards from change for the sake of change. All that is demanded under modern scientific management is that a proposed change in a standard must be scrutinized as carefully as the standard was scrutinized prior to its adoption, and further, that this work be done by experts as competent to do it as were those who originally framed the standard. Standards adopted and protected in this way produce the best that is known at any one time. Standardization practised in this way is a constant invitation to experimentation and improvement." Once performance has been standardized, the way is open to measure performance in terms of efficiency, and the power thus obtained of focusing the result of the work of numerous operations or departments in a single figure of efficiency (for example, the ability to express the work of a whole factory as having 82 per cent efficiency) is something which should not be forgotten when discussing standardization.

Mr. W. H. N. James (*communicated*): The values of the short-circuit currents to be used in fuse-testing which are suggested by certain foreign authorities (notably those mentioned in the American National Electric Code) certainly seem very high for small fuses, especially for those to be used for what the author has termed ordinary duty. In regard to the magnitude of the short-circuit current likely to be experienced by a fuse in practice, there are reasons leading us to suppose

* "Academic and Industrial Efficiency," Bulletin No. 5, Carnegie Foundation for the Advancement of Teaching.

that it is less than the value calculated from observations of the pressure drop across the fuse terminals when a known current is passing. In the first place, the fuse may blow before sufficient time has elapsed for the current to attain the full value settled by the resistance of the circuit; again, the supply pressure may fall somewhat as a result of the current taken by the short-circuit (this will not exert a material effect if the source of supply is of relatively considerable capacity); and, finally, the resistance of the heated fuse itself will tend to keep down the current-rush. In connection with the testing of fuses, it seems usual to employ a single fuse, and this has to take the entire duty of clearing the circuit, whereas in practice, though there are some circumstances where a single fuse is concerned, there will commonly be double-pole fuses (that is, there will be two fuses in series) and each will play its part in clearing the short-circuit current. In regard to the source of power to be used for applying short-circuit tests, the possibility of a drop in pressure resulting from the short-circuit current must be considered. Mr. Barnes and myself found, for the values of short-circuit current we considered to be representative of typical conditions, that the size and type of generator could be varied between wide limits without materially affecting the results. If, however, much larger values of short-circuit current are to be employed, I would suggest a large battery as the most suitable source of power, and failing this a high-speed direct-coupled set. I think it would be desirable to avoid rope- or belt-driven machines. Comparatively few tests seem to have been made on alternating-current circuits, where the conditions may be less severe. Whether any distinction in testing could or should be made is a matter for experiment and discussion. The rating of all enclosed fuses should be clearly indicated. The performance of many types is insufficiently stated on the label, and in each case the following information (or its equivalent) should be given as a minimum:—(1) The pressure of the circuit for which the fuse is intended. (2) The normal fusing current. (3) The full-load current for which the fuse is suitable. The author's remarks in regard to research on oil-break switches at home and abroad are very striking, and I suggest that the Institution might endeavour to supply information as to what steps are being taken (not merely discussed) in the various countries with a view to improving technical production after the war.

Mr. H. A. Ratcliff (*communicated*): The suggested standards given in Tables 1 and 2 are interesting, but I am surprised to see that the author includes such heavy ratings as 3,000 amperes. The connection made by clamping a copper strip between two nuts on a screwed stud may be quite sound mechanically, but electrically it is anything but good, and should be avoided wherever possible for currents in excess of 1,000 amperes. Some simple modification of the arrangement shown in Fig. 3 could surely be adopted for switches of smaller capacities than 3,000 amperes. The author's opinion that two-step oil switches are unnecessary for switching in cables is undoubtedly sound, but switches of this type are very effective in reducing the enormous current-rushes which may occur under certain conditions of voltage-wave and previous magnetization of the iron, when large transformers are switched into circuit. Not only are such rushes detrimental to the transformers, but they may in addition to tripping overload gear also possibly cause some types of balanced protective gear to operate. It is very questionable whether such auxiliary resistance contacts are of any practical value when breaking a heavy overload or short-circuit. On the subject of fuse-testing much could be written, and there is certainly need for agreement both as to the method of testing and also as to what constitutes a short-circuit. The best source of current for testing fuses is a battery of sufficiently large accumulators. If, however, a generator is used for the purpose it is frequently necessary to protect the fuse from the excessive pressure-rises which may occur at the instant of breaking circuit; this may be done by connecting a resistance in parallel with the fuse. The author suggests standardizing the various copper-nickel alloys, but omits to mention the extensively used nickel-chromium resistance materials, which have a much higher specific resistance and possess the further advantage, where space is limited, that they may if necessary be run at a very high temperature without any consequent deterioration. Undoubtedly the rating of motor starters is a matter for immediate standardization, as the demand for cheap articles has resulted in the obvious over-rating of many otherwise good starters. The requirements of the American National Electric Code are certainly severe and would no doubt suffice to condemn many of the starters on the English market. It is difficult in many cases to conduct tests such as those required by the American National Electric Code, and for that reason the following simple test which does not require the use of a motor possesses some advantage; good starters never fail to comply with it, whereas over-rated ones are invariably rejected:—The line and armature terminals to be connected to mains between which the pressure is that for which the starter is rated; the switch arm then to be moved over until the current attains the maximum permissible starting value, and the coils should not show any visible sign of damage after the current has been on for one minute.

Mr. J. F. Shipley (*communicated*): Shortly before the war commenced I spent a few hours in one of the research establishments in the A.E.G. switchgear works. I recollect that two of the research engineers were British. I was then very interested in the standardization of switchgear, and the engineer related to me the researches he had been conducting on low-tension knife switches and circuit-breakers, and repeated the chief experiments for me. One conclusion he had reached was that the size of a contact surface really had little to do with the carrying capacity of the joint. That appeared to be dependent upon three points of mechanical contact, necessarily of small area. These three "points" were usually in such a small area that they merged into one point when mechanical pressure was applied. The conductivity of the joint surface depended more upon the mechanical pressure than on anything else. As I have not seen the *Elektrotechnische Zeitschrift* since 1914, I do not know whether the results

of these researches were published, but it was the practice of the A.E.G. to ask their engineers to publish chosen portions of them if they were of universal interest. I am able to confirm the author's remarks on page 217 on the provision of special research and testing laboratories. One of these was attached to every department of the A.E.G. works, and there were at least 15 of them in existence when I was there. I peacefully penetrated into most of them. His estimate of the cost would be about right. It is incorrect to say that these testing laboratories were special; they were normal. The result of this work is now more evident to me than ever before. The firm I serve regularly receive inquiries, even at this date of the war, from South America based upon A.E.G. standards and catalogues. Every person, great or small, interested in the slightest degree in electrical engineering seems to be provided with a complete set of A.E.G. catalogues in his own language and with native prices, weights, and measures. Standardization does, however, fail occasionally. A certain mining company in South America had ordered a complete German electrical plant, which included a standard switchboard. Having been paid for partly before the War, it was built in September or October 1914, but the combined efforts of the British and German Admiralties prevented its reaching its neutral destination until late in 1915, when it was immediately erected and put into service. All went well as long as the load did not exceed about 25 per cent of full load. But at half load the busbars began to sag. At full load they made very respectable loops, and arcing commenced shortly after at the standardized concentric joints of the busbars and connectors, and a few seconds later these had melted too. The station was immediately shut down, and remained so for several days. The trouble was due, first, to German want of copper, and secondly to standardization. All the copper connectors, busbars, and joints on that switchboard had been replaced by zinc, and the sizes had, owing to standardization, not been increased at all. Now zinc melts at 419° C. and commences to flow at a much lower temperature; it has also about three times the resistance of copper, and its surface easily oxidizes. The Germans had neglected to alter the standards, with the result that that particular mine will not order any more German electrical equipment if they can help it. In undeveloped countries the need for standardized material is such that it is almost inconceivable to work without it; and the saving in time, money, and trouble is quite sufficient to make a purchaser go to the firm which standardizes, long before he thinks of looking at the material of one which does not. Up to the present the firms who have been most successful in introducing their equipment and in getting repeat orders have been those who have carried standardization to a very high degree. They were either American or German; why not British?

Dr. C. C. Garrard (*in reply*): I should like first of all to lay stress upon the great national importance of the question of standardization. In the past there has been too much jealousy between the various manufacturers. People are nowadays realizing, however, that it is necessary to look upon the subject from a broad-minded point of view. As several speakers have pointed out, standardization will in the first instance enable component parts to be made in large quantities by specialist manufacturers at very much cheaper prices than they have been made hitherto. Standardization, moreover, goes farther than this, in that it sets up standards of performance as well as standards of dimensions; for example, it is quite possible to set up a standard of operation of a telephone service or of an electric supply station. Having such a standard in such instances, the means are to hand for scientifically measuring the efficiency of such concerns.

I am very glad to hear from the President that action in the direction of standardization of heavy switchgear is likely, and especially that a strong Sub-Committee is to be set up within the Engineering Standards Committee to deal with the question. I would suggest that this Sub-Committee should make a preliminary survey of the ground indicating where standardization is necessary, where research is required, etc. The work could then be allocated to various Panels or Sub-Committees so that effective progress is made in a reasonable time. I think it is only by some such action that it is possible to catch up the position already attained in other countries.

I am heartily in agreement with the President's remarks regarding the desirability of securing the co-operation of the Local Sections of the Institution in the matter of research. It would be a very excellent idea if Local Research and Standardization Committees could be set up with the co-operation of the main Committee, especially for work suitable for the local conditions.

As regards the investigation of high-pressure phenomena, I am afraid that not much progress can be made without the establishment of a suitable large-scale laboratory. One has only to read the papers which have appeared in the *Proceedings* of the American Institute, in which the results of the investigations on the corona effect are given, to realize this. As an example of the importance of this matter, I have heard it asserted recently by a number of experienced engineers that in their opinion very high-voltage overhead transmission is not possible in parts of this country owing to atmospheric conditions. Such a question could only be settled experimentally, and it does not need any words of mine to bring home the profound importance of this to the future of the electric supply industry in this country.

I can also support the President in his statement that standardization is a very thorny question and necessitates much patience and hard work before arriving at any satisfactory conclusion.

Those most closely connected with the articles to be standardized are the best people to carry out the work. In this connection I should like to suggest that the Institution should take some steps with a view to forming a Committee, as suggested in the paper, to deal with the whole subject of house-service fittings.

Several speakers, among them Mr. Williams and Professor MacGregor-Morris, fear that standardization

might check improvement. I have dealt with this question in my reply to the discussion in Birmingham (see page 244). I should only like to add that in my opinion standardization promotes progress in that it prevents the dissipation of effort. Moreover, if the various people concerned are willing to pool their knowledge and experience nothing but rapid progress can result. Mr. Gill's remarks are very much to the point in this connection and I heartily agree with them.

Mr. Ellis and Captain Taylor raise the question of co-operation with users in this matter, and with this I heartily agree.

It is very interesting to hear of the tests which Mr. Ellis has carried out, but I venture to say that it would be very much better if the results of such tests could be published. One can easily understand the attitude of the manufacturer who sometimes hesitates before publishing the results of experiments, etc., as these may be the bread and butter of his business. These considerations, however, do not come in with an electric supply authority. If Mr. Ellis therefore, instead of slightly lifting the veil on his experiments and tests, could give full details I am sure he would earn the gratitude of the industry.

Mr. Ellis seems to prefer the use of large-power oil switches containing a minimum quantity of oil. Certainly, if there is any danger of the tank blowing off and the oil igniting, a small quantity of oil is desirable. I think, however, I am correct when I say that there is a strong tendency at the present day to discard these switches with a small amount of oil in favour of those with much larger tanks. In answer to Mr. Cowan also, I think I may say that this is the tendency in America.

I am totally unable to agree with Mr. Ellis' contention that the millivolt-drop test on contacts is out of place in a central station. Mr. Tallent-Bateman also raised this question and states that the heating test is best; but the heating is in proportion to the volt-drop. Moreover it is impossible to locate the source of heating very exactly on heavy copper connections. The millivolt-drop test is suitable for central station work, as it can be carried out during the normal running of the plant. By means of systematic measurements by a millivoltmeter it is possible to track down any faulty contact to its exact position, and I would strongly urge those speakers who have not used the method to give it their serious consideration.

Captain Taylor referred to the question of busbar reactances. I think there can be no doubt that reactances have rendered the super power-station possible. I quite agree with him that the mere quantity of oil in the oil switch is not the only consideration, but regard must be had for the distribution, head of oil, etc.

Mr. Cowan also referred to this point, and his description of the oil switches as used in South Africa is very interesting. I have referred to the tests on oil switches made in the A.E.G. Laboratory in Berlin, and if reference be made to the original paper it will be seen that a similar arrangement to that described by Mr. Cowan was experimented upon.

As regards the two-step oil switch, there is evidently a considerable difference of opinion, although both Captain Taylor and Mr. Gott support the system. I am afraid, however, I must adhere to the opinion expressed in the paper, that the simple switches are to be preferred.

Several speakers, including Mr. Le Maistre and Mr. Gott, have referred to the definition of "standardization." I think I have already made it clear, however, that there is a considerably wider meaning of the word "standardization" than the mere settlement of dimensions in certain articles, and I venture to think that this wider meaning will gradually become universal.

Mr. Cowan referred to the standardization of red metal. I am afraid my experiences of cast copper have been very unfortunate. Recently, however, "boron copper" has come to the front and certainly is worthy of investigation. If something could be done to secure cast metal which would have a conductivity approaching

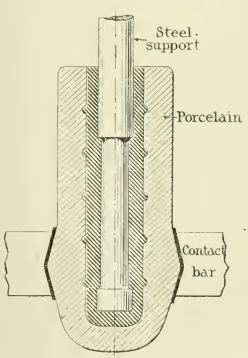


FIG. C.—Porcelain support without tensile stresses.

drawn copper it would be of vast utility. Professor MacGregor-Morris suggested that a standard of rolled aluminium should be set up. I quite agree. There is no doubt that for heavy busbars under normal conditions aluminium would show a saving in cost.

I quite agree with Mr. Berry's general remarks as to the way of going to work in standardization. It is, I think, not desirable that the use of any particular standard article should be made universally compulsory. The great objection to the compulsory adoption of a universal standard is that only in rare instances is one standard sufficient to suit all conditions. I think in the first instance the use of the standards should be voluntary. The great thing is to set the standards up, and then if they are good ones everybody is anxious to use them to the greatest possible extent.

I think there is no doubt Mr. Cowan's theory in regard to the resistance of a surface contact is correct, and the result he obtained in connection with the heating of an oil switch due to oxide of copper is very interesting

and shows the great necessity of the proper upkeep and cleaning of switchgear.

There is a matter in connection with the design of oil circuit-breakers to which I should like to refer. Captain Taylor, when referring to Fig. 6, said he had had the moving contact supporting porcelains in such breakers shear off. I am inclined to think, however, that Captain Taylor has confused the type of porcelain shown in Fig. 6 with another commonly used type. The section of the porcelain used in Fig. 6 is illustrated in Fig. C, and it will be seen that the central steel supporting-rod passes right through the porcelain to below the point of support. Consequently there are no tensile stresses in the porcelain. It is well known that porcelain is not well adapted for supporting tensile stresses. The other type to which I refer is

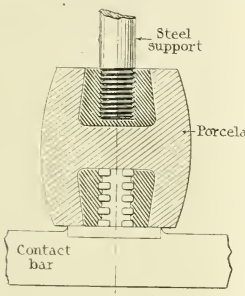


FIG. D.—Porcelain support with tensile stresses.

illustrated in Fig. D, and it will be seen that the whole of the stress in the porcelain is a tensile one. I had considerable experience a number of years ago with porcelain as in Fig. D, and can confirm Captain Taylor's remarks that breakage was not infrequent.

Captain Taylor has also instituted a comparison between the horizontal under-crossarm break and the vertical circular oil-pot circuit-breaker. There is no doubt that excellent breakers have been constructed on both principles. I think, however, the evolution is towards the former pattern. The fact that there is a tendency, with the former, for the break to be opened by the electromagnetic repulsive force of the current through the circuit breaker can be an advantage, as it certainly causes the circuit breaker to open-circuit more quickly and surely. There is no difficulty in making the retaining mechanism strong enough to keep the circuit breaker closed under normal conditions. With the second, or straight-line type, this phenomenon is not present; moreover, with this type it is usual, I believe, for the main current-carrying contacts to be in the open air with only the auxiliary contacts under oil. This arrangement was in use in this country 20 years ago and was given up in favour of the total submersion of all current-carrying parts in oil, which is, there can be no doubt, a very much more desirable arrangement.

I am in agreement in the main with the remarks of Mr. James.

With reference to Table 5, it is not intended to indicate that the currents mentioned in this table actually or necessarily flow through the fuse when the same is short-circuited. The figures in the table, however, undoubtedly constitute a criterion of the severity of the test. The actual current which will flow through the fuse, however, on short-circuit depends in a large measure upon the construction of the cut-out itself. This current, with some designs, would be much smaller than with others. No doubt this property of limiting the actual current which flows through the fuse on short-circuit explains to a great extent why one make of fuse is so much better than another.

With regard to Mr. Ratcliff's remarks as to making a connection between strip and stud for 3,000 amperes, it would certainly be very bad practice simply to clamp the strips between two nuts for such a current. If the 4-in. strip (Fig. 13) be used at 1,000 amperes per square inch, six such strips would be necessary and the connections would be made as follows:—One clamp nut, 2 strips; one spacing nut (Table 3), 2 strips; one spacing nut, 2 strips; and then another clamping nut on the outside. Instead, therefore, of there being two nuts only there would be four, with two ventilation ducts in the busbar. This would make a thoroughly sound job.

As regards the copper-nickel alloys I suggested a standardization of these for making starters and regulators. I do not think the nickel-chromium alloy is used much for this purpose but finds its chief application for heaters. Of course the same argument applies to the standardization of this wire as to the copper-nickel alloys.

Mr. Shipley's remarks are of extreme interest and should serve as a stimulus, if such be needed, to our increased activities in research and the like. I do not, however, agree that the example he gives of the zinc busbars has anything to do with standardization. Such action as he refers to could be better described by an altogether different word.

BIRMINGHAM LOCAL SECTION, 20 FEBRUARY, 1918.

Mr. F. Forrest: I suppose most of us when speaking of switchgear include in that term all switches, instruments, connections, and other apparatus required for controlling a circuit or circuits together with the means of supporting, insulating, and protecting such apparatus. It is when we think of the extent and variety of the apparatus included in the switchgear equipment of modern power stations that we appreciate the enormous amount of detail work and investigation which will have to be done before definite rules can be formulated for the standardization of all component parts of the switchgear on the lines suggested by the author.

Whilst I do not believe that complete standardization of switchgear and switchgear arrangements is possible or necessary, there are a great many items included in the term "switchgear" which might be standardized now by the various manufacturers, with advantage to both seller and purchaser, without waiting for the Engineering Standards Committee to issue rules. For instance, direct-current ammeter shunts should have a standard millivolt drop across them when carrying their full-load current. Current transformers should have a standard secondary current, and also a standard volt-ampere capacity. Instrument scales might be marked in a standard manner, and the instruments themselves standardized and improved, for they are now one of the least satisfactory items of present-day switchgear. Rheostat hand-wheels should have a standard direction of rotation for raising the pressure, and a standard number of turns for the full range of the rheostat. The two-step oil switches which the author suggests should be done away with are always likely to be required in connection with high-voltage induction motors, unless one is prepared to install choking coils connected permanently in circuit with the stator of the motor. The use of a two-step switch or of a choking coil permanently in circuit with the motor winding is not, as the author states, a "condonation of inferior insulation of the machine." The stator slot-area being of a fixed amount, the necessary reinforcing of the insulation of the end coils to withstand the high potential that momentarily exists between turns when switching in cannot be carried out, and means for preventing this high potential must therefore be installed. It is difficult to see how the standardization of switchgear arrangements can be introduced with advantage at the present time, and especially the standardization of complete cellular construction in connection with extra-high-tension switchgear. There is in fact some likelihood that the e.h.t. switchgear for large bulk supply generating stations in the future may consist of a simple arrangement of duplicate lead-covered cable busbars and connections, very strongly clamped and supported, with oil-immersed isolating switches, and with only the oil switch totally enclosed in a separate compartment. If the author's proposals were confined to details of switchgear apparatus only, they would receive almost universal support.

Mr. R. L. Goold: In the opening paragraph of the paper the author defines standardization. I venture to suggest that the old-fashioned secretive policy to which he refers is not the evil presenting serious difficulty. The real obstacle to complete standardization will be the existence of competition—the desire of one manufacturer to excel another. This, in my opinion, is an axiom of healthy progress in refinement of construction and evolution of design. Standardization is eminently desirable in matters such as the back-connection studs and nuts, the length of break, the area of the contact surfaces, and in other matters attending the fundamental switch function of conducting and breaking an electric current. As to a standardization of the general style of construction which the author proposes, this is, I think, a subject which is controversial. In the production of switchgear it is difficult to see how the standard switch would be obtained by the co-operative action on the part of designers and manufacturers to which the author refers. The solution would probably have to involve a process according to which each manufacturer, by research and experiment, and the utilization of his knowledge and experience, evolves, probably at some considerable expense to himself, that which he believes to be the most suitable design for a particular purpose. From a number of designs thus evolved it would be necessary to select the standard. Problems would then arise how the individual designer is to be compensated for his research and expense. And if a switch is adopted as a standard, what is the position if another design is subsequently produced which is admittedly better? I submit that it is impossible to deny that monopolies afforded by patents and design registrations present a serious problem in the progress of completé standardization. It cannot, I think, be said that the design of switch mechanism has attained a condition of perfection beyond the range of improvement. A good example of anti-standardization are the china bases of cut-outs and switches. The author mentions the variety of forms which these assume, and in many of the designs considerable advantages are attributed to matters which, *prima facie*, appear trivial. Large numbers of these have been protected by design registration, and for this and other reasons the tendency to dissimilarity among the different makes has become so pronounced that the manufacturers of these articles in the Potteries have established a rule by which they refuse to supply to one firm a design similar to that supplied to another. While in this branch of switchgear manufacture anti-standardization has no doubt been carried to an undue extreme, difficulties of complete standardization, such as those to which I have referred, still emerge. I therefore suggest that while every encouragement should be extended to standardization within certain limits, the plea for entire standardization should be advanced with caution lest it impede the evolution of improvement.

Mr. A. Krause: The author has called attention to what I consider to be a matter of equal importance to the opening up of new national activities, as without a proper amount of standardization advantage cannot result nationally. Standardization must not be made to mean the fettering of progress; research and experiment must be excluded from the domain of standardized products, but both these must be carried out systematically with a view to ultimate standardization. As an example of the advantage to be gained by standardization, I would refer to slate bases, a common enough requirement. These are worked by a dozen different firms, each making for most other trades in which slates are used; consequently each firm has a maximum variety of requirements, with resulting inefficiency and want of precision. Standardization is best carried out by the engineer who has both the practical and the scientific knowledge, with probably a greater breadth of view. The standard lampholder has not prevented new types being made as required, but for each new purpose they should be made alike by all manufacturers.

Mr. G. Rogers: I agree with the author that standardization of switchgear is urgently required from the point of view of the manufacturer, and also for the convenience of the customer. I know of scarcely any branch of switchgear the parts of which are standard, and engineers are constantly up against trouble and needless delay in emergency through the lack of interchangeability of switchgear. The whole matter is one of detail and common sense, and the time has surely come when, as suggested by the author, the Engineering Standards Committee, or a special sub-committee, should deal thoroughly and systematically with switch and controlling gear. Powers must then be obtained to enforce the adoption by manufacturers of the Committee's findings. If this is done, then the object for which this paper was written will be achieved. Some of the conclusions of the author are, perhaps, open to criticism. He suggests the standardization of millivolt drop for knife-switch and circuit-breaker contacts. I am of the opinion that in each case the standard should be simply the current density of the surface contacts. There would be two standards: one for flat surfaces and one for laminated brush contacts. In both cases the surfaces should be properly ground in. I agree with the author that the ordinary Whitworth threads for large-diameter studs are too coarse—the finer the thread, the better are the contacts and the more sensitive is the action of the nuts in drawing together a number of flat surfaces. This is particularly so when tinfoil is used between contact surfaces. Also all nut dimensions should be standardized so that the spanners on the job will fit any and every nut on the switchboard. I do not think that it is necessary to standardize the sizes of copper used in the building up of busbars. Certainly I think a much better and easier job can be made of heavy busbars with copper thicker than the author suggests. Many other details suggest themselves after one has read the paper, and mention might be made of the large variety of field rheostats and rheostat pedestals. It is no uncommon thing to see side by side two or more pedestals of different height and design, and sometimes of different rotation to "raise" or "lower" the voltage. Again, the details of the large number of indicating and integrating meters used on switchboards require careful consideration. Holding-down screws, and the size and position of terminals, should be standardized in order that the instruments could be interchangeable.

Mr. R. G. Jakeman: On referring to Table 1, which gives proposed screw-threads for back-connection studs, it would appear at first sight that the author has invented a new standard screw-thread. There are many objections to such a course and it might be expected that there are already sufficient standards in this line. On looking into the matter more closely, however, it will be seen that the first four on the list are practically the same as the standard Whitworth gas thread, of which the dimensions are as follows:—

Size	Diameter	Threads per inch
$1\frac{5}{8}$ in.	2 in. $+\frac{1}{64}$	11
$1\frac{3}{8}$,,	$1\frac{3}{4}$,,	11
$1\frac{1}{4}$,,	$1\frac{5}{8}$,, $+\frac{1}{32}$	11
$1\frac{1}{8}$,,	$1\frac{1}{2}$,,	11

The diameters between $1\frac{1}{2}$ inches and $\frac{5}{8}$ inch do not agree so well, but it would be advisable to try to adapt them rather than produce another standard. I agree with Mr. Forrest that it is practically impossible to insulate the first coils of large induction motors sufficiently to prevent breakdown. It is certainly the best practice to provide an external choking coil. This choking coil need not be very large and can be mounted on the shell of the motor near the terminals. There is no reason why it should not remain permanently in circuit, so that the author's objection to it on the ground that it necessitates an extra step on the oil switch does not hold good. I am sorry to see that the suggested standards for copper-strip connections are shown in inches and not in millimetres. I think the standards would last for a greater number of years if the metric system were employed.

Mr. R. Orsettich: The discussion has shown that the views regarding standardization are very divergent. This is due to the fact that the paper does not distinguish between internal and external standardization. By internal standardization I mean that affecting the manufacture in the works, whereas by external I mean the rules and arrangements which are made with regard to the user of the apparatus. The internal standardization, apart from the importance to the manufacturer, affects the industry as a whole in so far as it is the basis for the production of parts or materials by firms and specialists—for instance, china insulators, copper strips, screws, carbons, etc. The external standardization, on the other hand, greatly affects the operation, replacements, and repairs of plant. The great responsibility in fixing rules of this kind is that they must not limit future developments, but rather they must make room for expansion. The rules must therefore be mainly concerned with the drawing up of a definite specification to enable buyers to state comprehensively all their requirements, and also to identify and compare the apparatus offered. They furthermore must state clearly and uniformly the tests with which the apparatus will have to comply and the minimum conditions of acceptance. In fixing such rules the experience of operation must be available, and where not available special equivalent tests must be proposed. Very important among these are the endurance tests which have been brought forward by several Standardizing Committees with a view to fixing the minimum number of times which any apparatus has to operate satisfactorily before requiring attention or repair. No suggestion appears to have been made in the paper as to the nature or conditions for such tests. The specification proposed for brass seems to be unsatisfactory, in so far as it leaves out the content of lead. This is an intentional constituent of brass up to a maximum of 2 per cent because it greatly improves the machining qualities of the metal. On the other hand, it is bound to reduce the conductivity of the brass, and it is therefore important that it should be reckoned with in a standard specification. The same remark applies to a lesser extent to the specification for gunmetal. I wish to take the strongest exception to the proposed table of threads for studs of switches. There are already three well-known standards of threads,

the Whitworth, the fine thread, and the B.A. thread. These are perhaps the most extensively recognized standards in engineering, and the creation of a new standard for the sake of saving a slight amount of material is unwarranted, compared with the enormous difficulties that such a change may cause if a repair is required in some distant country. That the standard shape of thread is retained is of no use whatever as soon as the number of threads per inch is altered. In dealing with oil switches there is no mention of difference in the types of contacts, i.e. whether they should be solid or laminated. Also the very important question of the connections between the insulator and the rod operating the switch is not discussed. An important question affecting circuit breakers should be the heating of the brushes and of the springs compressing these brushes. This is more important than the current density and should be kept below 20 degrees C. rise. In connection with resistance wires, only copper-nickel alloys are mentioned, whereas there are a number of other materials on the market and in daily use. The specification for such materials, apart from the physical constants, should mention the importance of their being non-oxidizing and non-rusting. Their expansion coefficient at high temperatures should be stated, as this affects the sagging of the wires in the resistance boxes, and sometimes causes the slipping of the turns along the rod which supports them. In connection with starters and controllers, limits should be fixed for the maximum voltage variation across the no-volt coil before this coil comes into operation. The ability of the starter to stand vibration without tripping is also of practical importance.

Mr. W. Wilson: I should like to say a few words regarding the subject of this paper, as one who is familiar with the electrical industry in some of the most distant parts of the British Dominions. It is unfortunately noticeable that the plant in use in those regions is largely the product of foreign firms. Now the reason for this is not by any means to be found in local preference. As a matter of fact, a preferential tariff in favour of British makers is in existence, while the patriotic sentiment of the Colonial engineers and purchasers would lead them to choose a British-made article, even if it would entail a slight loss, other things of course being equal. In spite of this favourable tendency, however, the British manufacturing firms do not compete successfully with the foreigners; and there is thus need of a change of some kind. There seems no doubt, in my mind, that this state of things is largely due to the lack of standardization in our own industry. The manufacturers abroad are able to turn out much larger numbers of any one article than we are, and thereby secure all the advantages of standardized production. To anyone who has carried out work on "quick-repetition" lines, which are employed so effectively in America, the old individual method seems uneconomical in the extreme. Not long ago I was concerned in the manufacture of a delicate appliance for war purposes; and as the order amounted to many thousands, it was possible to standardize every part of the process. The result was that whereas a single article, made by itself, would have cost one or more pounds, the figure was reduced, under the repetition system, to well under 6d. It seems to me that such results are what we should aim at in our work. There are only two requirements, namely, to increase the output, and to standardize everything as far as we possibly can. Towards the former end, care should be taken that the Dominions are supplied with the British articles that they ask for, and which will be needed in very much larger numbers in the near future than ever before. With regard to the exact way in which standardization will be turned to account, the author has given details of certain small parts which he proposes shall be of uniform dimensions with all makes of switchgear. There is no doubt that a considerable gain would be effected if all the minor components were so standardized that they could be manufactured in bulk and bought in from, perhaps, one maker by the various firms. This was the practice in vogue in the example of quick-repetition to which I have referred, where, although the pay-roll at this particular works was in the neighbourhood of 12,000, practically all the small components were made outside. If this were done in our own case, only the largest parts, and those peculiar to the individual firms, would require to be made in merely moderate numbers. In this way standardization would effect an important saving that might well, in itself, justify its adoption.

Mr. D. Martin: I agree that switchgear design is still in such a state of flux that except in some minor details the time is not yet ripe for complete standardization. Nevertheless it is good to aim at an ideal, and so far as the minor component parts such as the threads of studs, bolts and nuts, surface contacts, break in knife switches, and the like, the time is ripe; but so far as type is concerned, particularly for large power stations, finality is not nearly reached nor likely to be for some years yet. Standardization is inclined to stifle individual initiative if applied too early, and this would be a hindrance to progress. Do not think I am against standardization. Far from it. My experience at the Ministry of Munitions during the past two years makes me a confirmed believer in it, and I think the time is ripe, so far as it concerns low-tension gear. I think it will be agreed that the war has taught us among many other things at least one important lesson, namely, intensified production. Midland manufacturers had learnt it even before the war, and a development of it had already taken deep root, namely, specialization. Specialization is a factor in standardization. The days of a manufacturer attempting to make a dozen articles at a cost of 20s. which he could buy from a specialist for 20 pence have gone, never to return. The tendency in this direction is a natural one, and a great point in its favour is that it does not disturb labour conditions. In practice it has the reverse effect. It increases not only production but also the amount of labour employed, and it is an object-lesson to the pessimist. One has only to take any of the numerous examples such as cotton thread, buttons, pens, cycles, or the like, for a proof that intensified production increases the demand, no doubt because the articles made become available to a greater number. As a further example in this connection, while on service in the fighting zone in France I was much impressed

by the fact that electricity apparently was of universal adoption even for the lowliest labourer's cottage before the war broke out. For intensified production there must be no waste of either labour or material, and, in this, standardization is an aid to success. The war has taught us another essential lesson, namely, the necessity of co-operation among producers, employer and employed. Again it has to a great extent eliminated that feeling of petty jealousy between competitors in the same trade by compelling one to be content to undertake what work the machinery available would tackle. All of these are gains in the great commercial fight after the war in which the essential ground-work to success will be standardization. The author has very aptly demonstrated how both the Germans and the Swiss have taught us a lesson, and unless we wish to see the old pre-war system resumed, we must make it worth while for customers to buy from us. The British are essentially not only an adaptable race but one possessing initiative, but we must not drift in this matter; rather must we concentrate all our energies as near to the ideal as possible. One of the essentials of standardization is simplicity, and in this matter I am surprised the author does not once refer to the simplest type, namely, ironclad switchgear. He seems inclined to favour the cellular type. One of the speakers has referred to the two large power-station schemes in hand where he says lead-covered cables are to be used for the main busbars. It may be news to some that in both these 20,000-volt three-phase a.c. schemes, the switchgear and the busbars to be installed will be of the totally enclosed ironclad type. It is being installed on its merits as well as on account of cost. Its simplicity, its relative small size, its mechanical strength in the event of an oil-fume explosion, its ease of manipulation, and its foolproof features are all qualities it possesses over the flat-back slate type or the cellular systems. The mere fact that it is ironclad provides an easy means of protection without the highly complicated and delicate trip mechanisms so familiar to all in the flat back or cellular type. One might compare the building of the brickwork and concrete cells shown in Figs. 15 and 16, complicated as they are and requiring expert labour, with the building of a fresh pattern for each phase and circuit of a multiphase system. This expense is eliminated in the ironclad type, as only one such pattern is necessary. On the ground of simplicity alone I am surprised the author has not referred to it, in view of the fact that simplicity is an essential to standardization and specialization, and to be logical one must refer to it. In conclusion, I need hardly say that this paper, so far as it goes, only whets one's appetite for more. It only emphasizes the immensity of the problem and generally one is impelled to agree with the author in his agitation for standardization where that is helpful, as it would be in low-tension work and up to 6,000 volts. It is a subject which must receive immediate attention even before the cessation of hostilities if this country is to hold its position in the great after-the-war competition for trade.

Mr. H. W. Dipple: I am of the opinion that any standardization of knife switches should specify for grinding and finishing of the contact surfaces, so that the whole of the available area is used. I would point out that in large central-battery telephone exchanges it is important that the resistance of the main circuits between the batteries and the point of distribution to the individual circuits be kept as low as possible in order to avoid cross-talk. The Post Office usually specify the contact area to be not less than one square inch per 200 amperes, and the conducting parts to be not less than one square inch per 500 amperes. I have seen cases in new installations where the switches as received from the manufacturers were in such a state of adjustment that only about one-third of the available area of contact was used, consequently the switches had to be adjusted on the site. The same remarks apply also to cut-outs of the slip type with porcelain or fibre handles. I have seen such fuses received from the makers with only about one-quarter of the available contact area actually in use.

Mr. C. Jones (*communicated*): It is becoming increasingly evident that maximum production for export in the future must be our life line. The standardization of details is to be strongly advocated and would be a great advantage. I think if manufacturers would engage designers who have had practical experience in the running and maintenance of apparatus, users would not be so likely to find fault with their products. These remarks are confined to the user's point of view. Mining switchgear has progressed considerably during the last few years, but there is still room for improvement, especially as regards standardization. In case of mining switch-pillars, it would be a great advantage to have a standard height. Another most essential part of a mining equipment is the standard plug suitable for (1) gate end boxes, (2) coal-cutters, (3) coal-conveyor motors and all other portable apparatus in and about a mine. The plug and socket should be designed with a view to their being easily fitted to any of the apparatus just mentioned. There is a great number of special extensible unit gear applicable to mines. A standard interconnecting piece, so that one maker's appliance can be fitted against another, appears to be desirable. Another desirable feature that could with advantage be standardized for mines, is a protective device for a motor with an electrically operated switch which comes into operation every time the controller is switched on or off, the switch being so arranged that it could not be tampered with. The question of starters is also one that deserves special consideration. There is no reason why starters above 10 horse-power could not be constructed with standard resistance coils, face-plate contact, etc., and with judicious connections could be made to have different ratings to give a minimum number of different sizes from, say, 10 to 100 horse-power for ratings from 15 seconds to half a minute. The rating of large power-supply switchgear is a matter that must be tackled, as it is a question of switches operating when faults develop and when there is 20,000 to 50,000 kw. behind them. Then there is the question of fixed and free handle-type switches. Why not make a standard of the free handle type? It has also occurred to me that standard connecting socket plugs suitable for making quick connections for use with wattmeters on motor line panels would be of great

service by allowing measurements of power factor, etc., to be taken during the routine examination of the electrical installation, without having to make temporary connections, which is not possible with some of the fool-proof gear now in use. The author has referred to the millivolt drop at the jaws of knife switches. In view of the Mining Rule which calls for all metallic parts of the apparatus to have a conductivity equal to 50 per cent of that of the inner conductor, it is necessary to suggest to some manufacturers that this test should be applied to determine the continuity and efficient earthing of the metal cases of instruments, etc. The standardization of contact plates, controller fingers, and the renewable tips of controlling gear, would be welcomed. Standard sizes are very desirable for the outer diameter, fixing holes, connecting terminals, etc., of electrical instruments, and also for the bolting pins, lugs, and internal wiring of control gear. It is essential that switches should be as accessible as possible and provision made for readily and easily lowering and raising the oil tanks. This is most difficult in some types of gear. I entirely agree with the author in regard to standardization of switchgear, but care must be taken that no hard-and-fast rules are laid down to prevent the development of such apparatus as a result of experience, which is, after all, the deciding factor.

Mr. H. Kramer (*communicated*): I think the present time is unique for effecting standardization in most industries. I suggest that every manufacturer of switchgear should send a design or specification, or preferably a sample, to a Committee appointed for the purpose of considering the adoption of the most desirable standard. There must be scores of simple apparatus such as small and large switches, fuses, cable boxes, switchboard sections, terminals, ammeters and voltmeters, starters, regulators and controllers, and a large number of other similar gear, ready for selection by such a Standards Committee. Surely after nearly 30 years of designing and amending such apparatus, we are no less in a position than America or the enemy countries to make up our minds which of those essential articles should immediately be standardized. A schedule of articles concerned should therefore be determined at the first meeting of such a Committee. I should like to add that all the more complicated switchgear must *nolens volens* be left over for further development and can be added from time to time. Standard specifications should most certainly be left over until the range of samples and propositions has been thoroughly inspected by every member of the Committee, for I fear that were standard specifications issued even as a preliminary, it would almost definitely defer any agreement. There is no apparatus more recklessly designed than electrical switchgear. The difference in the execution and often in the price of a switch or fuse or starter for the same work is appalling. Merits are, however, often found in articles which might be condemned by the Committee as a whole, and for these reasons every manufacturer, even the smallest makers, should be invited to send his sample "standard." We all know that America and several Continental countries have already their standards, and if engineers in this country cannot agree on a reasonable standard construction for at least the simpler apparatus, the commercial or financial aspect of the future will do it for them. It is the coming Trusts who will be largely responsible for the introduction of standards. They will readily fix upon a standard for every type of any switchgear article that is made in large quantities, and the apparatus designed and fixed upon by the biggest Trust will then be the standard of the country. The present stocks and manufacturing methods will easily be exhausted by the time standard switchgear makes its appearance. Jealousy among competitors as to whose design is the best and should be used—either on account of its cheapness or extra great solidity—ought not to stand in the way. Originality of design and inventive thought are flexible and can surely be diverted into the development of more complicated switchgear, in which there is still a very great demand for original and research work. Some switchgear manufacturers claim a certain privilege—either for having pioneered some of the switchgear which comes under the standardization proposition, or for having dominated the market for cheapness, or for claiming special potential features, and so forth. These or other reasons might induce them to oppose standardization. To them the proposed Standards Committee will, I think, not make in vain the patriotic appeal to throw their claims into the national melting pot for the benefit of the country's trade in the near future and to accept compensations, if at all desired, where their types specially appeal to the Committee for acceptance. Such funds should be subscribed by manufacturers or additional Government assistance might be applied for. Samples should therefore be accompanied by claims for compensation—if the claimant will not voluntarily forgo pecuniary remuneration. Only by so testing the interested parties can the Committee reach an early conclusion as to how far standardization of British switchgear is likely to be carried to a practical conclusion.

Dr. C. C. Garrard (*in reply*): I think I am correct in saying that the very many interesting points brought out in the discussion justified the writing of the paper. The subject is of course a tremendous one, and it is only possible to refer to a few phases of it in one paper. I did not deal with the matter of current transformers, ammeter shunts, or instruments mentioned by Mr. Forrest, as these are receiving attention at the moment on the part of the competent authority. I quite agree, however, with Mr. Forrest's remarks on these points, especially with the statement that a current transformer should withstand a current through its primary equal to at least 20 times its full-load current without damage.

Mr. Forrest speaks rather disparagingly of instruments in general, but, if I may say so, I think his remarks would have been truer a few years ago when price-cutting without any standardization among manufacturers resulted in a deplorable lowering of quality. Within the last few years, however, I think I may say that an improvement has been effected in this direction.

Mr. Forrest gives very valuable testimony as to the value of reactance coils in series with a high-tension

induction motor in preventing concentration of potential across the end-turns when switching on. I think that the discussion, in general, supports my contention that the two-step oil switch is undesirable, and that the only occasion when a switching reactance is desirable is when switching on a high-tension induction motor, in which case a fixed coil permanently in circuit with the stator is the best arrangement. Mr. Jakeman supports this argument, as also does Mr. Orsettich.

Several speakers, among them Mr. Goold, appear to think that the effect of standardization would be to hinder progress, either by eliminating competition between the various manufacturers or by the stereotyping of apparatus. In my opinion the direct opposite is the case, and Mr. Krause hits the nail on the head in this connection when he says that standardization and research must go hand in hand. This is a statement with which I heartily agree and it should be the keynote of all our work.

In a large and complicated industry like our own, if there are no standards every new-comer, on entering the field, has to start at the beginning. Over and over again I have met men who come forward with inventions and suggestions which have been discarded or superseded years before. Now, standardization to a great extent prevents this, in that it provides a jumping-off place for new advances and improvements. In other words it provides an ever-widening and ever-growing foundation upon which new advances can be built. In the absence of standardization, the inventor or designer is compelled to start so low down that he often never reaches the level represented by the combined and sifted-out knowledge and achievement upon which he otherwise would have been able to start building. It is really surprising that nowadays it should be necessary to argue for the principle of standardization in general. Everybody who has had experience in a factory of any pretensions at all knows that works' standardization is absolutely necessary nowadays, and the national standardization advocated in the paper only carries us a step further.

Mr. Orsettich, Mr. Jakeman, and Mr. Rogers criticize the standard I proposed for the threads on the back-connection stems of switches. All I can say is that the points they raise were very carefully considered before the workshop standards given by me were adopted. The only suggestion I can make, therefore, in the event of the standardization authorities taking the matter up, is that the arguments mentioned should be placed before them so that they may consider all points of view.

I do not like the idea of using tinfoil between copper contacts as suggested by Mr. Rogers. Tinfoil, it is true, will turn a bad joint into a possible one. I think, however, if the workmanship is good and the surfaces are tinned the use of tinfoil in not necessary.

Mr. Rogers opposes very strongly the use of the 4 in. × 1/8 in. copper busbar section advocated by me. All I can say in reply thereto is that I can show Mr. Rogers many stations in this country with busbars of all capacities made from this section, and I think if he saw them he would admit that they are first-class jobs. I quite agree with his contention that the cables at the back of switchboards should be fire-proof. Unfortunately, owing to the want of standardization, it is difficult to get hold of such fire-proof cables quickly.

One effect of improved standardization of switchgear would be that it would be easy to obtain standard detail parts from specialized manufacturers. This point is mentioned by Mr. Krause and Mr. Wilson. A firm of electrical engineers should not have to bother itself with the manufacture of such details, which have really nothing to do with electrical engineering. Mr. Krause's remarks as regards the developments in this direction in the United States are, I believe, very true.

Mr. Jones's remarks are very interesting, showing the effect of standardization as applied to the use of electricity in coal mines. His remarks certainly give food for thought to electrical manufacturers. I think I can safely say, however, that during recent years a tremendous improvement has taken place in mining switchgear. Moreover, this is a direct result of the establishment of a standard; in this case a standard of quality, that is to say the Home Office Rules for the use of electricity in mines. I am afraid his suggestion to use only a few sizes of starters above 10 horse-power, altering the connections for different sizes, would lead to unnecessary expense. The great thing is to secure a standard range of sizes, and this matter is now being considered, I understand, by the Engineering Standards Committee. I quite agree that circuit-breakers should be standardized on the basis of the free handle, and there is urgent need for the standardization of gate-end plugs. The suggestion for the use of easily altered testing terminals for wattmeters and the like is an excellent one. Such arrangements are used a good deal, I believe, in America. The question of standard controller fingers is over-ripe, and a solution should really be arrived at without further loss of time.

Mr. Orsettich gives a very excellent classification of the different forms of standardization, with which I quite concur, and he instances a number of points which require standardization, with which I also agree. As I have pointed out, the paper could not be comprehensive. It was only intended to deal with a number of points representing the more urgent requirements.

As regards the use of copper-nickel alloys for resistances, I suggested these because I think they have stood the test of time and are almost universally used by, at any rate, first-class makers. As far as I am aware these alloys are impervious to sea air. With reference to the suggested specifications for brass and gunmetal, I should like to make it clear that I had in view only the standardization of current-carrying alloys, and for these I think conductivity is of more importance than free turning properties.

I would again raise the point of the urgent necessity of the standardization of brass. I should like to make a definite suggestion that a Committee should be set up in Birmingham working under a delegated authority from the Engineering Standards Committee to deal with this question. This could contain representatives from our Local Section, from the Institute of Metals, the Brass Masters' Association, the University, the local manufacturers, trade unions, etc. If a representative committee could be got together with a competent

secretary, it should not take very long, or great expense, to produce a series of specifications which would codify the present knowledge of the art and do away with the existing state of chaos.

Mr. Martin and Mr. Forrest refer to the question of cellular switchboard construction for high voltages, and I am glad that Mr. Forrest supports the cellular type. With reference to the use of lead cable for busbars, doubtless this is an excellent idea. In my opinion, however, it should not replace the cellular construction but should be an addition to the same and form an additional safeguard.

Mr. Dipple refers to the specification, in connection with telephone power boards, that the current density in apparatus should not exceed 500 amperes per square inch. I am not a telephone expert, so I do not profess to be able to say whether this is necessary or not. I must confess, however, I do not see what influence such a requirement as regards, for example, the switchgear controlling the motors driving the generator for charging the cells in a telephone exchange could have upon the efficiency of the telephone service. I can, however, bear witness to the disadvantage such a specification has in necessitating the use of special switchgear on all such telephone power boards.

With regard to Mr. Kramer's communication, I am afraid the revolutionary methods of standardization advocated by him would be impracticable. I think the only possible procedure is along the general lines laid down by the Engineering Standards Committee, but with a widened and extended scope in directions similar to those I have ventured to indicate in the paper.

GALILEO AND MAGNETISM: A STUDY IN LOADSTONES.

By J. J. Fahie, Member.

(*Paper received 25 March*, 1918.)

"Were we to distinguish the ranks of men by their genius and capacity more than by their virtue and usefulness to the public, great philosophers would certainly challenge the first rank, and must be placed at the top of mankind. So rare is this character that, perhaps, there has not as yet been more than two in the world who can lay a just claim to it. At least, Galileo and Newton seem to me so far to excel all the rest that I cannot admit any other into the same class with them" (*Hume's Essays*: "On the Middle Station of Life").

The recent acquisition * by the Institution of an excellent portrait of Galileo, through the munificence of our Past President, Mr. C. P. Sparks, has suggested to me the idea of placing before members a short account of Galileo's early researches in magnetism. With this before us we can claim and venerate his name as a pioneer in one of the fields of our own activity in this Institution. Galileo's study of the loadstone or natural magnet did not take him far. The subject was only one (an episode so to speak) of the many studies which crowded his long life. Yet in this, as in all the others, he has left the imprint of his genius in ineffaceable characters: Nullum quod tetigit non ornavit.

Vincenzio Viviani, himself a distinguished mathematician, but who liked to be known as "the last disciple of Galileo," tells us, in a biography of his great master that "towards the end of 1604 he had completed a long study of the properties of the loadstone, and after many and varied experiments had found a sure way of arming any given stone so as to make it sustain a weight of iron 80 to 100 times greater than could be supported by the stone unarmed—a result which had not been reached by any investigator up to that time." We can now take the date back to 1602 and possibly earlier. Thus, in a letter dated 8th August of that year a Venetian friend, Gian. Francesco Sagredo, acknowledges the receipt of a stone armed by the exquisite art of Galileo. Then, there is a letter from Paolo Sarpi, another Venetian friend, to Galileo (2 September, 1602) in which he alludes to their recent discussion on the inclination of the loadstone to the horizon according to latitude—a discussion which was based, as the context shows, on Book V of Gilbert's "De Magnete," published in 1600. From these and other evidences Professor Favaro of Padua University—the great authority on all things Galileian—concludes that "our philosopher had been engaged on these studies for a considerable time, if not to a date anterior to the issue of Gilbert's book, certainly very soon after, when he verified all the experiments of the English philosopher and instituted new ones of his own."

It appears that during the long summer vacations at Padua, Galileo was wont to spend his holidays in Florence, where from about 1601 he gave private lessons in the sciences to the young Prince Cosimo de Medici. In the summer of 1607 he had evidently been rehearsing the wonderful properties of loadstones, and having inspired his pupil with a keen desire to have one he, on returning to Padua, was able to send him a specimen, which he had "picked up in Venice, about ½ lb. in weight, not elegant in form, but very powerful." He adds that a friend of his (Sagredo, as it later transpired) had another fine stone which was beautifully shaped and weighed about 5 lb., and which he was disposed to part with at a price—400 scudi (about £90) was hinted at.

* See *Institution Notes*, No. 4, page 18.

The Prince desired to possess this stone also, but thought the price excessive. Thereupon ensued a long higgling correspondence which is of interest to us only in so far as it records all that we know of these early researches.

In a letter early in 1608 to Belisario Vinta, the Grand Duke's Chief Secretary, Galileo, after referring to the money question, goes on to say—"The stone weighs about 5 lb. (Florentine). Now, the marvellous thing is, not that it weighs so little, but that it sustains more than its own weight, or $5\frac{1}{2}$ lb. of iron, as I have made it to do in these few days; and I believe that I can make it sustain still more before it leaves my hands. It requires experience and investigation to develop its full power. In the first place, the points or poles where the virtue is most robust are two and only two, and these must be found with diligence. Then, the sustaining force depends as much on the quality of the armature as on the stone itself, as not every kind of iron and not every size and shape are equally supported; but highly wrought steel of a particular size and figure is most powerfully attracted. Then again, if the armatures be shifted a little to one side or the other of the poles there will be a great reduction in the weight that can be carried. In the last four days, during which I have had the stone in my possession, I have experimented carefully and have managed to make it carry a lb. more than its owner was ever able to do; and I hope after preparing some pieces of finest steel to make it sustain very much more."

He then describes an interesting case of what is now known as superposed magnetism:—"I have also observed in this stone another admirable effect which I have not met with in any other, namely, that the same pole repels or attracts the same piece of iron according to distance. Thus, placing an iron ball on a smooth and level table, and quickly presenting the stone at about one finger's distance, the ball moves away and can be chased about at pleasure. But sharply withdraw the stone to a distance of about four fingers, the ball now moves towards it, and with a little dexterity can be made to follow it about. It never approaches nearer than one finger, at which distance repulsion ensues." Subsequent experiments showed that the ball in this case was not of pure iron but of the nature of magnetized steel, pure iron being attracted under all circumstances.*

Evidently these marvels decided Prince Cosimo; for in a short time the bargain was concluded at 100 doubloons, or about 100 guineas. Meanwhile, Galileo was making fresh observations, which we find in his letter of 3 May, 1608, to Belisario Vinta—"I send for his Highness the loadstone which, after many trials, I have made to sustain a weight of 12 lb., or more than double its own, and this is not the half of its marvellous properties. I am confident that had I more time and more suitable tools at my disposal † I could have done better. I have fashioned the two armatures in the form of anchors, in allusion to the fable of a stone so large and powerful as to hold securely a ship's anchor. This form is also convenient for attaching weights to measure its holding capacity. I have purposely not made these anchors equal to the greatest weights that I know the stone will carry, firstly, to leave a margin of safety, so that it will hold them firmly when presented at the poles, and secondly, because I am of opinion that its holding power will vary according to locality with respect to the poles of the great magnet, the earth: that, whereas along the equinoctial line both poles will be of equal strength, one will be more powerful than the other in the northern hemisphere, and proportionately to its vicinity to the pole; and vice versa in the southern hemisphere. Hence I am led to think that the more powerful pole of this stone sustains here in Padua somewhat more than it can in the more southerly latitude of Florence or Pisa, and vice versa, as regards the other pole. Therefore I would like that a trial of this be made and with the greatest diligence.

"To each of the two anchors I have tied separate pieces of iron and other small weights, which in sum represent the maxima that the poles will carry. In Florence, being a more southerly latitude than Padua, the pole marked 'Austral' may bear somewhat less and the other somewhat more than they do here.* I have marked the poles so that one can see readily where the armatures should be applied, that with the greater weight should be attached to the more robust pole marked A (*austral*), and the one less heavily weighted to the weaker pole marked B (*boreal*), taking care to apply them at the same time. I have found, not without great astonishment, that the stone supports more willingly the two weights together than one of them alone. Thus, a piece of iron, so heavy as not to be borne when applied alone, will be held if at the same time another piece is applied to the other pole.†

"I have in mind some other artifices to render the stone still more marvellously powerful, and I am certain that I shall not fail, but I have not the means of doing so here. I believe I can make it sustain four times its own weight, or 20 lb., which, for such a large stone, is something very admirable. Indeed, I have no doubt that with proper cutting it can be made to support 30, and even 40 lb.

"I have noticed in regard to this stone, not only that it never tires of holding a weight, but that with time it invigorates itself the more, i.e. the longer it sustains a weight the more it gains in strength, and the more weight it can carry! In allusion to this miraculous property, I would suggest to his Highness that one of the following would be a suitable motto for the stone—'Vim Facit Amor,' or, borrowing from Petrarch, 'Amor ne Sforza,' since it is symbolical, according to my idea, of the power vouchsafed by God to the just and lawful prince over his subjects, which power ought to be such that with amorous violence it draws to itself in an ever increasing way

* See an interesting explanation of this case by Jules Jamin in *Comptes Rendus* for November 1875.

† During the years 1599–1610 we find from entries in Galileo's day-books that he had a workshop in his house in Padua, where men were busy under his personal supervision, making magnets, magnetic compasses for ships, thermometers, geometrical and military compasses, and, latterly, telescopes. He also had, at least for a time, a printing press, where his first published work—"Le operazioni delli Compasso Geometrico e Militare"—was printed "in casa dell' Autore, 1606).

* In these passages he mixes up two properties of the magnet (1) its portative force and (2) its directive force or inclination.

† This acute observation occurs also in Gilbert's "De Magnete," Bk. ii., chap. 22. Silvanus Thompson ("Notes on the De Magnete," 1901, p. 48) says: "Even now this fact is not as well known as it ought to be. Only so recently as 1861 Siemens patented the device of fastening a mass of iron to one end of an electromagnet in order to increase the power of the other end."

the loyalty and devotion of its vassals; and this it will do when the royal power is exercised not in oppressing but in raising the people committed to its care." *

Unfortunately, the Sagredo stone was lost in after years (as also, apparently, the smaller one picked up in Venice). In 1698 a search was made in Florence at the request of Leibnitz, but it was nowhere to be found. Leibnitz deplored this as a loss to science, "realizing that fresh observations and experiments upon it would probably further the advance of magnetic philosophy, with advantage to geography and navigation; and even might lead to new discoveries in the arcana of nature."

The "other artifices" referred to by Galileo in his last-quoted letter consisted in breaking up large stones, shaping the best pieces so as to bring out their maximum of polarity, and providing them with suitable armatures; with the result that the portative force of the selected pieces greatly exceeded his own first successes, and far surpassed Gilbert's achievements in the same direction. Thus, in Chapter 17, Book ii, of the "De Magnete," the English philosopher speaks of a stone (weight not given) which normally could sustain 4 oz. of iron, but which when capped, according to his method, with best steel, smoothed, shining, even, and close fitting, could support 12 oz. "But," he goes on, "the greatest force of a combining or rather united nature is seen when two stones, armed with iron caps, are so joined by their concurrent (commonly called contrary) ends that they mutually attract and raise one another. In this way a weight of 20 oz. of iron is raised, when either stone unarmed would allure only 4 oz."

Now, Galileo went far beyond this, since he was able, by his "other artifices," to fashion small stones of extraordinary power. Of such a one he speaks in a letter to Cesare Marsili, dated 27 June, 1626. It weighed 6 oz., and unarmed could support 1 oz. only, but when suitably armed it was able to sustain 150 oz. or 25 times its own weight. He had this stone by him when writing his "Dialogue" of 1632, where he speaks of it as still in his possession. Later, he appears to have presented it to the Grand Duke Ferdinando II, as we gather from Castelli's "Discorso sopra la Calamita," *circa* 1639–40—"I have seen a small stone only 6 oz. in weight, armed with iron by the exquisite diligence of Signor Galileo, and presented by him to the Most Serene Grand Duke, which holds suspended 15 lb. of iron, worked in the form of a sepulchre."

This stone is now preserved in the Tribuna di Galileo, Florence, and after 300 years holds as firmly as ever its weight of 15 lb. The weight, as just stated, is in the form of a tomb—a form which was probably suggested by the legend of Mohammed's coffin supported in mid-air by loadstones. Through the great courtesy of my friend, Professor Favaro, I am able to illustrate this interesting relic from a photograph which was made expressly for me *

Galileo had always a great admiration for Gilbert (il grandissimo filosofo) and for his great work, "De Magnete." The book, which by the way came into his hands by chance,† appealed to him in a special way for two reasons—first, because its arguments traversed many of the principles of the Aristotelian school, and secondly, because it contained a number of original experiments, coupled with philosophical reflections of a far-reaching kind—all of which appealed to his own free and daring spirit. Thus, in his letter to the Grand Duchess Cristina (above quoted) he says "From the work of that 'grandissimo filosofo,' so exhaustive of its subject and so full of evident demonstrations, there can be no question that our earth in its primary and universal substance is none other than a great globe of loadstone."

Then, in the third Day of his celebrated "Dialogue on the Chief Systems of the World—the Ptolemaic and the Copernican," 1632, discussing the third rotation of the earth as postulated by Copernicus, he introduces Gilbert's theory—"But what will Simplicio 'one of the three speakers in the dialogue' say if to the reasons already adduced we should add an admirable intrinsic virtue of the earth—namely, looking with its determinate parts 'the poles' towards determinate parts of the firmament." Then, in answer to some depreciatory remarks of Sagredo, Salviati (who represents Galileo himself in the dialogue) says—"I praise extremely, I admire this author, and I envy him for that a conceit so stupendous 'of the earth being a loadstone' should come into his mind, which had been handled by so many sublime wits, and hit upon by none. I think him, moreover, worthy of extraordinary applause for the many new and true observations that he has made to the discomfiture of so many fabling authors, who write not from their own knowledge, but retail whatever they hear spoken of by the foolish vulgar, never seeking to assure themselves of the same by experiment—perhaps because they are unwilling to lessen the bulk of their books."‡ He goes on to show the plausibility of Gilbert's hypothesis, and chides him for his hesitating rejection of the fable that a stone freely pivoted on its axis will revolve once in 24 hours, thus superseding clocks—"I must speak of one particular, to which I wish he had not lent an ear, I mean that in case a little sphere of loadstone be exactly librated it will revolve on itself. I see no reason at all why it should do so." In the course of this debate he discourses on the properties of the loadstone, summarizing his own early observations, notably on their increased carrying power when provided with armatures according to his method.

* In a letter of the same period, 19 December, 1608, to the Grand Duchess Cristina, Galileo proposed to commemorate the approaching marriage of her son Prince Cosimo by a loadstone shaped as a ball to symbolize the prince (five balls were the arms of the Medici family), from which depended numerous bits of iron to represent his faithful (attached) subjects, with the motto "Vim Facit Amor." He also suggested the striking of gold and silver medals, one side to bear the figure of the prince, with the legend "Magnus Magnes Cosmus," and on the reverse a copy of the loadstone ball with its dependent irons and motto.

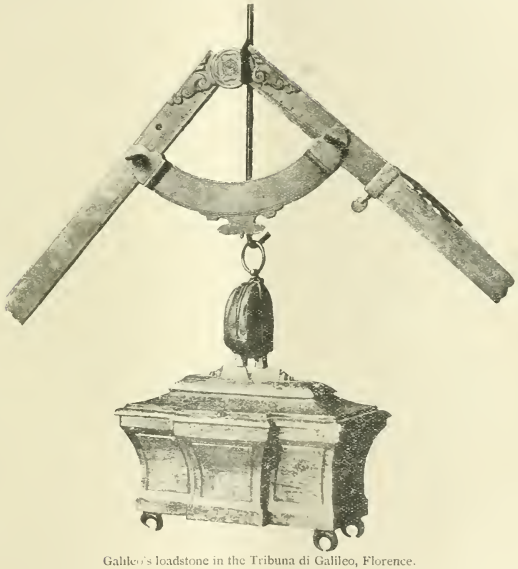
* The rule or sector seen above the loadstone is Galileo's Geometrical and Military Compass, which was in great repute all over Europe for many years. The Editor of the Florence edition of Galileo's Works, 1718, mentions another small stone fashioned by Galileo, and of still more extraordinary power, in that weighing only three-tenths of a grain it could sustain 121 grains (Preface, vol. 1, p. 46). This, if true, beats Sir Isaac Newton's which he wore set in a ring. It weighed 3 grains, and was able to support 746 grains.

† "Probably the book would never have come into my hands if a peripatetic philosopher of great fame had not given it to me, as I believe to free his library from its contagion" ("Dialogue," 1632). The book is now in the National Library, Florence, and bears Galileo's autograph signature.

‡ Cf. "De Magnete" (English edition, 1900, p. 2), where Gilbert trounces these fabling authors in almost the same words.

It was probably while "searching for loadstones amongst the lapidaries and antiquaries of Venice" that Galileo fell in with one of those peripatetic vendors of magnetic telegraphs (so numerous in the sixteenth and seventeenth centuries) of whom he gives us a characteristic account.* In the dialogue just mentioned he makes Sagredo say—"You remind me of one who offered to sell me a secret art, which, by a certain sympathy between magnetized needles, would enable me to speak to one who might be two or three thousand miles away. I told him that I would become

These notes contain all that we know of Galileo's researches in magnetism, and, as said at the outset, they do not take us far; but there is a reason for this. In 1609 he invented the telescope which opened up to him some marvels of the heavens hitherto undreamt of, and these practically absorbed the next 20 years of his life. What remained was given up to preparing and publishing what he himself considered to be his greatest and most enduring work—his life-long thoughts and investigations concerning the laws of motion. These were collected in "Dialoghi delle



Galileo's loadstone in the Tribuna di Galileo, Florence.

the purchaser willingly, provided only that I might first make trial of the art, and that it would be sufficient for this purpose if I place myself in one room and he in another. He replied that in so short a distance the action would be hardly discernible; whereupon I dismissed the fellow, saying that it was not convenient for me just then to go to Cairo or Muscovy, but that if he chose to go there himself I would remain in Venice and attend to the rest."

* The story of the sympathetic needle telegraph, which so beautifully foreshadows the inventions of our day, was based on the sympathy which was supposed to exist between needles that had been touched by the same magnet, whereby an intercourse could be maintained between distant friends, since every movement given to one needle would induce a corresponding movement in the other (see my "History of Electric Telegraphy," 1887, chap. i).

Nuove Scienze," first published in Leyden in 1638—a work which made smooth the way for Newton and his "Principia," 1687. "These discoveries of Galileo," says Lagrange ("Mécanique Analytique"), "did not bring him while living as much celebrity as those which he had made in the heavens; but to-day his work in mechanics forms the most solid and the real part of satellites, of the phases of Venus, of the sun-spots, etc., wanted only a telescope and assiduity. But it required the glory of this great man. The discovery of Jupiter's an extraordinary genius to unravel the laws of nature in phenomena which one has always under the eye, but the explanation of which had always baffled the researches of philosophers."

DISCUSSION ON

"ELECTRICAL COOKING AS APPLIED TO LARGE KITCHENS." *

NEWCASTLE LOCAL SECTION, 14 JANUARY, 1918.

Mr. A. H. W. Marshall: The author has, I think, clearly made out a case for electrical cooking on the large scale from the standpoint of economy in food, and under present circumstances economy in food is of greater importance than economy in fuel. As to the latter there are several considerations which tend to modify the result of the comparison usually drawn between the number of heat units which are required in the one case, when cooking is done electrically, and in the other when coal or other fuel is used direct. In the first place, the thermal efficiency of electrical generating plant is rapidly on the increase; the cost and loss of transporting and distributing coal is a serious item; and as can be clearly seen from the slides which the author has shown, the application of the heat units electrically is far more efficiently done than could possibly be the case with either coal or gas. From the power-load point of view, electrical kitchens should be a welcome addition of supply undertakings, as the maximum demands occur at the usual off-peak hours. I am interested to hear of so many successful installations being at work, and I venture to think that our municipal authorities will find electrical cooking apparatus of great value in setting up communal kitchens, as they are now doing, to relieve the food situation in the more thickly populated parts of the country.

Mr. W. F. T. Pinkney: The design of electric cooking plants is a matter for engineers, and the massive switchboard shown on the first slide indicates that such installations are obviously an engineer's job. With regard to the maintenance figures given for the four installations, it was pointed out that in the case of installation D the cost is unusually high, due to the cooking plant being considerably overloaded. Can the author tell us why the maintenance of installation A is so very low? Is it because the installation has been efficiently handled by the users all through? I consider that the maintenance cost should decrease in time as the users become more familiar with electric cooking and abuse the plant less. The author suggests an Advisory Committee, and the President also was in favour of this. I should like to hear the author's views of the composition of such a Committee. The supply authorities, architects, heating engineers, and cooking experts ought all to be represented. I am in agreement with regard to co-operation between electrical supply authorities. There has been little in the past, and this is a subject upon which co-operation would do a great deal of good. It will only be a short time before the demand for electric cooking will have to be met, and in two years' time the demand will be so great that supply authorities will have to be in a position to deal with it. In previous discussions on this paper many of the questions asked have been relative to domestic cooking, but this paper is on an entirely different problem. In the domestic cooking load, consideration must be given to the capacity of mains and to substation peaks in residential districts, but these points hardly arise in connection with electrical canteens in works. Mr. Marshall has referred to the question of thermal efficiency, but it is not always remembered that there are no heat losses in the chimneys in electric cooking.

Mr. C. Turnbull: There is a great future for electrical cooking and the author has by no means exaggerated its possibilities. Makers of apparatus will do well to profit by the experience of men like the author, and to strengthen the heating elements. These naturally suffer from the dampness and greasiness of their surroundings and breakdowns must occur unless all parts are made very substantially. What is also very important is that elements should be arranged for easy repair. I have used apparatus in which it is very difficult to change the elements, and it is even necessary to send parts back to the makers at great expense and loss of time for repairs which, in well-designed apparatus, might have been done on the spot in a short time. It seems probable that the spread of heating and cooking will bring a speedy end to direct-current distribution. The immense demands of the future must be met by short distributors fed with alternating current by frequent substations. This system will prevent undue drop of pressure, while it limits faults to small areas, where they can easily be traced and repaired with a minimum of interruption to the supply.

Mr. V. O. Davis: I take it that water from the calorifier is used for washing up dishes, etc. I understand that one installation is in connection with a works canteen and it might be advisable to run an arrangement of that sort in connection with baths for the workers. Looking at the slides which the author showed, I was rather struck by the position of the switches, which in most cases were above the apparatus. I do not know the size of the ovens, but what impresses me is that they may be difficult of access, although I suppose the objection to the switches being at the side is the extra floor space occupied. I should like to ask if the current charts represent any particular day or an average over a number of days. The character of the chart would be affected by the kind of joints and food being cooked on any particular day. Reference has been made to the need for technical men to attend to electrical cooking apparatus; I take it that in the larger installations there is a responsible man to attend to blown fuses, etc. With regard to the question of renewals of hot-plates, etc., I do not know whether all units are connected in parallel, but in the case of small grills or ovens if the units are not made divisible into

* Paper by Mr. W. A. Gillott (see pages 92, 153, and 203).

very small portions, the failure of one unit may seriously affect the cooking capabilities of the apparatus, inasmuch as a renewal would be difficult if not impossible to make quickly on account of the heat in the apparatus.

Mr. F. O. Hunt: The author refers to the method of connecting the elements and recommends series-parallel connection. While the slides were being shown I failed to see any indication of the kind of switches. As two paths in parallel would appear to need a somewhat complex switching arrangement perhaps the author would give us some further details. The analysis of faults is very interesting and I was struck with the very large proportion of wiring faults. They are, I suppose, those which arise between the controlling switches and the elements. I should be glad to know what class of insulation was used on the wiring, particularly that upon the ovens. The paper is so useful that one hardly likes to make a complaint, but there is so much vagueness in the minds of many people that it is necessary for those who write on the subject to be careful to use the words "heat" and "temperature" in their proper senses. On page 93 we should read "provide the correct temperature."

Mr. W. Sowerby also took part in the discussion. The substance of his remarks will be found in the discussion before the Institution (see page 102).

Mr. W. A. Gillott (*in reply*): The competitors of electrical cooking apparatus generally refer to the number of therms obtained for one penny as against the number they can supply for a like sum, but they utilized to the best advantage. (2) The working conditions were clearly understood before the scheme was drawn up; therefore the plant was suitably designed (3) The kitchen staff were shown how to use the apparatus to its best advantage, and the proprietors realizing the improved results from such instruction used the plant accordingly. The maintenance costs will naturally be less if the apparatus is properly used. Regarding the suggested Advisory Committee, I may say in reply to Mr. Pinkney, broadly speaking, that the Committee or Association would be composed of selected members of supply authorities, manufacturers and other interested bodies, who would endeavour to establish close co-operation, standardize certain parts of the apparatus, and generally improve the standing of the electrical cooking and heating business, by educating station engineers as to the possibilities of electrical cooking apparatus and how to employ it successfully, and advising them on the behaviour of the plant and how it will generally affect their mains, plant, and tariffs, also to educate the public by well-organized publicity campaigns, etc.

Mr. Sowerby's statement of his experience with electrical cooking apparatus and speaking as a business man with such a wide knowledge of catering, is an excellent testimonial for electrical cooking, especially so when one realizes that the amount he was prepared to pay for electricity for catering for 1,500 persons per day was not reached, although the actual number of persons catered for was very much in excess of that

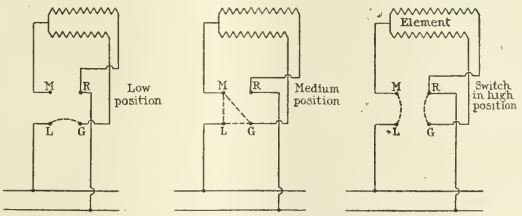


FIG. A. FIG. B. FIG. C.

Series-parallel connections of three-heat switches.

never compare the efficiencies of the different apparatus. It is well known that electrical cooking apparatus has an efficiency of approximately 90 per cent, as against a maximum of 15 per cent for other forms of cooking plant. When the subject is viewed from the standpoint of therms usefully employed, electricity is the most economical. Mr. Marshall rightly points out that supply authorities should welcome the additional load, as it generally improves the station load-factor without any capital expenditure on generating plant.

I agree with Mr. Pinkney that the design and lay-out of large kitchens is an engineer's job. The low maintenance of installation A is due to several reasons:— (1) The experience gained on other installations was

figure. Further comment by me is superfluous. The general behaviour of the plant and the results obtained prove that Mr. Sowerby is giving the apparatus the careful handling he advocates.

The difficulties referred to by Mr. Turnbull as to replacements are very rapidly disappearing, and in the large apparatus as described in the paper, comparatively speaking no trouble is experienced in renewing any defective parts. Manufacturers have made and are still making certain improvements to eliminate wiring and earthing troubles. These troubles have been the most prominent in the past, but with the apparatus now supplied, this class of fault seldom appears.

I am in agreement with Mr. Turnbull as to the future of direct-current distribution for supply networks. The establishment of large kitchens throughout the country will more or less hasten the adoption of high-tension feeders with transformers at short intervals for low-tension distribution.

In reply to Mr. Davis, the calorifiers are used for tea-making. The hot water from the domestic boiler is passed through a coil which is surrounded by water drawn from the main. The action of the domestic hot water passing through the coil heats the water in the calorifier to approximately 150° F., at which temperature it is discharged into the urns for boiling for tea-making. The switchboard fixed above the apparatus is approximately 5 feet from the ground, and is in quite a convenient position to operate. I do not advocate switches fixed on the side of apparatus; they are apt to give trouble due to heat from the ovens, etc., and are not so easily read. Regarding load curves, I would refer Mr. Davis to my reply to the Scottish discussion on this point (see page 207). It is not necessary to employ an electrician for maintenance purposes on the installation referred to; the apparatus is so designed that faults affect only a very small portion of the plant and in the majority of cases do not seriously inconvenience the cooking.

Mr. Hunt desires further information as to series-parallel connections. Figs. A, B, and C herewith indicate the paths of current at the "low," "medium," and "high" positions. The wiring faults were mostly met with in the terminal boxes at the back of the oven, in the flexible tube from the hot-plates and in the connections from the oven elements to the terminal chamber. The class of wire used was asbestos-covered nickel. I am sorry I must disagree with Mr. Hunt as to the interpretation of "heat" and "temperature." The word "heat" on page 93 is correct. The statement is not made to indicate a certain temperature: "to provide the correct heat" refers to a moist heat to keep the food in perfect condition.

The publication of the load curves on page 100 has created considerable interest both in London and throughout the provincial centres, particularly in respect as to how the load comes on and fits in with the station load-curves. In consequence of this, I have prepared a new curve (Fig. D) clearly showing how the cooking curve corresponds to the station curve. It is interesting to note how well the cooking load tends to fill up the valleys in the station load, the rise of one coinciding with a fall of the other—a most desirable state of affairs. This chart should convince central station engineers supplying a general industrial load that electrical cooking apparatus is really a necessary connection to provide good business. The curves were taken in February 1917, the cooking curve being the summation of installations A, B, C, and D, and the other the station load, which of course includes the cooking load, the ratio being approximately 580 to 1. I do not think any further remarks are necessary by me, as these curves are self-explanatory.

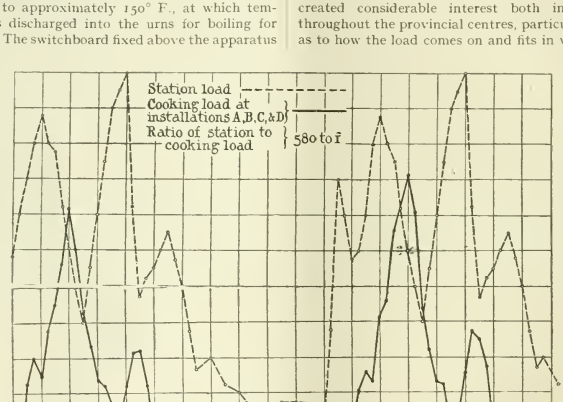

Station load
Cooking load at installations A,B,C,&D
Ratio of station to cooking load
580 to 1
8 10 12 2 4 6 8 10 12 2 4 6 8 10 12 2 4 6 8 10
Noon
Midnight
Noon

FIG. D.

JIEE 56 (1918)

THE EVOLUTION OF THE THERMIONIC VALVE.

By R. L. Smith-Rose, B.Sc., Student

(*Paper read before the* Students' Section, 22 *January*, 1918.)

Synopsis.

I. Elementary thermionics.
II. The Fleming oscillation valve.
III. The De Forest audion.
IV. The Lieben-Reisz valve.
V. The pure electron discharge valves; the kenotron and pliotron.
VI. The use of the thermionic valve as a rectifier, amplifier, and generator of alternating currents.

I. Elementary Thermionics.

The term "thermionic" currents was first applied by Professor O. W. Richardson, in 1902, to the currents obtained by the emission of electricity from solid bodies raised to a temperature of incandescence. Since then the term has come into very general use in dealing with this subject, and the valves used for radio-telegraphy and other purposes, which depend upon this phenomenon for their action, are most suitably designated by the title "Thermionic," or more briefly, "Ionic Valves."

Although it is nearly 200 years since it was first observed that the air in the neighbourhood of red-hot metals is a conductor of electricity, the chief advance in our knowledge of this phenomenon has taken place during the last 20 or 30 years. Among the earlier investigators, Guthrie in 1873 was the first to call attention to the distinction between positive and negative electrification.* He showed that a red-hot iron ball in air could retain a charge of negative but not of positive electricity, whereas when the ball was raised to a white heat it could not retain either a positive or negative charge.

The first systematic investigations were carried out by Elster and Geitel † during the years 1882–9. They studied in great detail the charge acquired by an insulated metal plate mounted close to a metallic filament within a glass bulb, under different conditions of filament temperature and gas pressure.

When the gas is air or oxygen at atmospheric pressure, the metal plate receives a positive charge which increases as the temperature of the filament is increased, until this is at a yellow heat. As the temperature is raised above this point the charge diminishes until, with the filament at a bright white heat, the charge received by the plate is very small. When the pressure of the gas inside the vessel is reduced, the charge received by the plate diminishes, and as the exhaustion proceeds a point is reached at which the charge changes sign, and for high filament temperatures and low gas pressures the charge on the plate reaches a large negative value.

* *Philosophical Magazine*, 1873, Ser. 4, vol. 46, p. 257.
† *Wiedemann's Annalen*, 1882–1889.

Both the sign and magnitude of the electrification are influenced by the nature of the substance comprising the filament, and also by the nature of the gas. For example, Elster and Geitel showed that in hydrogen the plate acquired a negative charge, even at atmospheric pressure.

At the Philadelphia Exhibition in 1884 Edison exhibited a discovery made by him during his investigations upon incandescent electric lamps.* The phenomenon which has since become generally known as the "Edison effect" is briefly as follows:—

A small, insulated metal plate is sealed into an incandescent lamp between the legs of the horse-shoe-shaped filament. When the filament is made incandescent by direct current and a galvanometer is connected between the insulated plate and the negative end of the filament, practically no current will be observed flowing through the galvanometer; whereas if the galvanometer is connected between the plate and the positive end of the filament a current will be observed flowing through the galvanometer, in direction from the filament to the plate, the current amounting to two or three milliamperes under suitable conditions. Neither Edison nor Sir William Preece, who subsequently carried out some experiments on this effect, gave any explanation of the phenomenon, nor was any practical application made of it.

Professor J. A. Fleming † in 1890 showed that when the negative leg of the carbon loop was surrounded by a cylinder of either a metal or an insulating substance, the Edison effect almost entirely disappeared; and other experiments of a similar nature showed that the effect was due to passage of negative electricity from the incandescent filament to the cold electrode, an occurrence which Elster and Geitel, by a somewhat different method, had previously demonstrated in very high vacua.

Fleming also showed that the Edison effect is obtained, although to a very much smaller degree, when using platinum instead of carbon for the incandescent filament.

At this time the existence of electrons was unknown, and the flow of current between the incandescent filament and the metal plate was attributed to the passage of negatively charged carbon atoms. This view was also apparently supported by the fact that both carbons and platinum give off very fine dust if they do not actually volatilize at high temperatures, as shown by the familiar deposit of carbon or metal on the glass walls of an evacuated vessel in which a filament has been glowing for a long period.

* Dyer and Martix: "Edison, his Life and Inventions," vol. 2.
† *Proceedings of the Royal Institution*, 1890.

In 1899, however, Sir J. J. Thomson announced his epoch-making discoveries concerning masses much smaller than atoms, carrying a charge of negative electricity, which were first called "corpuscles" but are now generally known as "electrons" and are still regarded as the ultimate units of negative electricity. These electrons were shown to be the carriers of the negative electricity in the cathode rays present in the high-tension discharge through a vacuum tube, and from measurements made in Sir J. J. Thomson's classical experiments it was shown that while each electron carries the same charge as that carried by a hydrogen atom its mass is equal to approximately only 1/1,800th of the mass of a hydrogen atom.*

Similar measurements showed that in the case of a carbon filament glowing in hydrogen at a very low pressure the negative electricity is given off by the filament in the form of free electrons.†

It was subsequently proved by Wehnelt that the electric current emanating from a lime-covered platinum cathode (the well-known Wehnelt cathode) is carried in the same manner by these negatively charged corpuscles,‡ and that the current from such a cathode is much greater than that obtained from the platinum alone.

Hence it may be said that when a metal or carbon filament is rendered incandescent in a highly exhausted vessel, there is a continual evaporation or emanation of negative electricity from it in the form of electrons, the rate of such emanation being dependent in the first place on the nature and temperature of the glowing filament, and on the nature and pressure of the surrounding gas.

This emission of electrons is readily explained by the electron theory, which assumes that these negatively charged corpuscles are disseminated through metals and carbon at all temperatures; they are in constant vibratory motion similar to that of the molecules of a gas, and are free to move in any direction under the influence of an electric force. These free electrons are normally retained within the metal by the electric force at the surface, which acts in a similar manner to the force at the surface of a liquid, tending to prevent the molecules of the liquid escaping into the region above it. If the velocity of any electron is sufficiently high its kinetic energy may be great enough to carry it through the surface layer, and so enable it to escape from the metal into the surrounding space. Since the average velocity of the vibratory motion increases rapidly with the temperature, then as the temperature increases, more and more of the electrons will be able to get through the surface layer and escape from the metal, the whole process being exactly analogous to the evaporation of a liquid with increasing temperature.

Applying the electron theory in this manner Professor O. W. Richardson found that the rate of emission of electricity from incandescent bodies could be expressed by an equation of the form

$$N = a\sqrt{T}\, e^{-bT},$$

where N = number of electrons emitted per square centimetre of the hot body per second,
T = absolute temperature of the body,
and a and b are constants.

Richardson's measurements of the current obtained from a hot wire at different temperatures agree well with a formula of this form, and from his observations on different substances he gives the following values for the constants a and b *:—

For carbon: $a = 10^{34}$; $b = 9{\cdot}8 \times 10^4$.
For platinum: $a = 7{\cdot}5 \times 10^{25}$; $b = 4{\cdot}93 \times 10^4$.

These figures show that the emission from carbon is much greater than that from platinum. The rate of emission from tungsten at different temperatures, as calculated from an equation of the above form by Dr. I. Langmuir, is shown in Fig. 1.

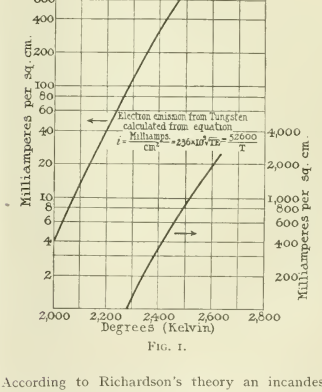


Fig. 1.

According to Richardson's theory an incandescent metal at any temperature emits electrons at a definite rate, which is independent of the electric field surrounding the hot body. If there is no electric field in the space surrounding the incandescent body, the electrons emitted return to the body and are re-absorbed. If, however, a positively charged body is brought near the heated solid, the electrons emitted will be drawn towards and absorbed by this body, their passage across the intervening space constituting an electric current flowing from the hot filament as cathode to the positively charged body as anode. The currents obtained in this manner were termed by Richardson "thermionic currents," a term which has since come into very general use.

If a negatively charged body is brought near the hot filament, the electrons will be repelled from it and will

* J. J. Thomson: "Conduction of Electricity through Gases," 2nd edition, chaps. v. and vi.
† J. J. Thomson: *Philosophical Magazine*, 1899, vol. 48, p. 547.
‡ Wehnelt: *Philosophical Magazine*, 1905, vol. 10, p. 80.

* J. J. Thomson: "Conduction of Electricity through Gases," 2nd edition, p. 201.

ultimately return to the filament in a similar manner to the case in which there is no field external to the filament.

Viewed in this manner, the electron emission is independent of the flow of a thermionic current, the latter only taking place when a positively charged electrode is brought near the glowing filament. As the potential of this electrode is increased, an increasing proportion of the electrons will be attracted towards and absorbed by it, until finally a point is reached at which all the electrons emitted by the hot cathode are absorbed by the cold anode, and any further increase in potential of the latter will produce no increase in the current flowing to it. At this stage the thermionic current is said to be "saturated," and the magnitude of this current will be equal to the total charge carried by all the electrons emitted per second by the hot cathode.

The theory, as thus put forward, would apparently give a satisfactory explanation, both qualitative and quantitative, of elementary thermionic phenomena; but there are many experimental results which are not so readily explained and which have brought to light one important feature which must be borne in mind when comparing the theoretical with the experimental results. The above theory takes no account of the action of the gaseous atmosphere surrounding the hot cathode, and it has now been well established that, unless very special precautions are taken to exclude it, the residual gas present in our so-called high vacua exerts a very marked influence upon the thermionic emission from any heated body enclosed in an exhausted vessel.

For instance, it has already been stated that when a metal wire is heated to a dull-red heat the first effect consists in the production of positive ions round the wire, which increase in number as the temperature of the wire is raised up to a certain value. Above this value of the temperature, negative ions make their appearance, and these increase at a greater rate than the positive ions, until finally the sign of the resultant charge given off by the metal is negative. The presence of oxygen at pressures approaching one atmosphere favours the emission of the positive charge, while a diminished gas pressure or the presence of hydrogen has a marked effect in increasing the number of negative ions.

This action of the residual gas in the space surrounding the heated body, and a similar action due to the presence of slight impurities in the heated body itself, have been subjected to much investigation since Richardson first put forward his theory, and the results have emphasized the importance of taking these considerations into account. H. A. Wilson has shown that the electron emission from a hot platinum wire can be reduced to 1/250,000th of its former value by a preliminary boiling of the platinum wire in nitric acid to free it from the hydrogen which it so readily occludes on its surface.* The admission of a little hydrogen brought the current back to its former value. On one occasion during these experiments when a little phosphorus accidentally got into the wire the emission was enormously increased. In all cases, however, he found the variation of the emission with temperature could be expressed by the relation given above. Some experiments carried out by Pring and Parker in 1912 showed also that the thermionic currents obtained from incandescent carbon in a vacuum decreased to extremely small values as the carbon is very carefully purified and the vacuum improved.*

Richardson also has shown that the positive emission from a heated wire is of a transitory nature. If the metal is heated at a constant temperature, the emission of positive ions falls off rapidly with time, the rate of decay increasing rapidly as the temperature is increased.

The results obtained by these and other investigators led to considerable doubt being thrown on Richardson's theory, and it was suggested that the thermionic currents obtained in the majority of cases, if not all cases, were due to chemical action arising from the impurities in the heated wire or the gas surrounding it, and that if a perfectly pure metal were heated in a perfect vacuum there would be no electron emission from it.

A very common example illustrating how small is the electron emission from an incandescent metal in a high vacuum is afforded in the ordinary tungsten-filament incandescent lamp. The vacuum inside a tungsten lamp is very high, probably of the order of one-millionth of a millimetre of mercury after the lamp has been burning for some time, while the high efficiency of the lamp is due to the refractory nature of the metal (tungsten), enabling it to be run at such a high temperature without fear of its melting. It is evident that in the ordinary lamp the current flowing from one part of the filament to the other must be very small, whereas according to Richardson's equation and experimental results the thermionic emission from tungsten at temperatures near its melting point might amount to several amperes per square centimetre of its surface.

Dr. Irving Langmuir, however, has recently studied in great detail the thermionic currents from tungsten filaments in extremely high vacua, the pressures used being of the order of one-millionth of a millimetre of mercury or less; and he has shown that the smallness of the currents previously obtained was due not to the failure of the filament to emit electrons but to the potentials applied to the anode being insufficient to enable the space surrounding the filament to carry the currents which could otherwise be obtained.† As a direct result of his investigations he concludes "that the electron emission from heated metal is a true property of the metals themselves and is not, as has so often been thought, a secondary effect due to the presence of gas."

In a typical experiment of Dr. Langmuir's two single-loop tungsten filaments were mounted in a bulb, which was then exhausted to the highest possible degree, utilizing special methods of exhaust and of treating the electrodes to free them from all occluded gas. One of the filaments was heated by the electric current and was used as the cathode, while the other filament served as the anode. A constant positive potential

* H. A. Wilson: *Philosophical Transactions*, 1903, vol. 202, p. 243.

* Pring and Parker: *Ibid.*, 1912, vol. 23, p. 102.

† I. Langmuir: *Proceedings of the Institute of Radio Engineers*, 1915, vol. 3, p. 261; *General Electric Review*, 1915, vol. 18, p. 327; and *Electrician*, 1915, vol. 75, p. 240.

was applied to the anode in series with a galvanometer, and by varying the cathode heating current, the relation between the thermionic current measured by the galvanometer and the temperature of the cathode was obtained and plotted in the form of a curve. This curve representing the thermionic current as a function of the temperature consisted essentially of two parts: during the first part the current increased according to Richardson's equation, and was independent of the voltage and of the shape and size of the anode; whilst during the second part of the curve the current was influenced by both of these factors. If the dimensions of the anode and its potential are maintained constant the current finally reaches a saturation value, and any further increase in temperature of the cathode produces practically no increase in the thermionic current. The

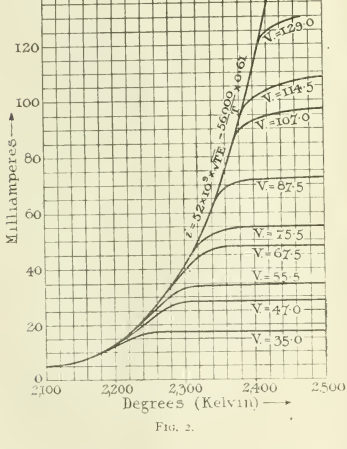


FIG. 2.

greater the potential at which the anode is maintained, the greater will be the value of the saturation current, and the higher will be the temperature to which the cathode must be raised before this saturation value is reached.

Fig. 2 shows a typical set of current-temperature curves obtained in the manner described above for different voltages applied to the anode. It will be observed that the early parts of all the curves coincide with the curve plotted from Richardson's equation

This limitation of the thermionic current by the potential applied to the anode was found to be due to the electrons carrying the current constituting an electric "space charge" between the electrodes, which repelled the electrons escaping from the hot filament causing them to return to it. Langmuir has calculated the effect of this space charge, and finds that in any bulb the maximum thermionic current that can be carried by the space between the cathode and anode is proportional to the potential difference between the electrodes raised to the power $3/2$, and his experimental results are in complete accordance with this law in the cases where the vacuum is so high that there is no appreciable positive ionization within the bulb.*

The presence of a very minute trace of gas within the bulb, however, may lead to the formation of positive ions sufficient to neutralize to a large extent the electronic space charge, and so greatly increase the current-carrying capacity of the space. For instance, the presence of mercury vapour at a pressure of 10^{-5} mm. has been found, under suitable conditions, completely to neutralize the effect of the space charge, so that a current of 0·1 ampere was obtained with 25 volts on the anode, whereas without the mercury vapour a pressure of over 200 volts was necessary to draw this current through the space.

Apart from this enormous effect on the current-carrying capacity of the space, the presence of a gas or vapour within the bulb exerts a considerable influence upon the thermionic emission from the cathode. But Langmuir found, contrary to the previously generally accepted opinion, that when the cathode is of pure tungsten the effect of any gas present is to decrease rather than increase the electronic emission. For example, it is found that the presence of oxygen or a gas containing oxygen such as water vapour, at a pressure of 10^{-6} mm. will cut down the electronic emission to a small fraction of the value obtained in a high vacuum.

This reduction of the emission by the presence of a gas is probably due to some chemical action, for it has been found that the inert gases of the argon group produce no such effect, and this fact has been employed in one type of rectifying valve to obtain neutralization of the space charge effect without reducing the electron emission from the tungsten cathode.†

Having thus briefly reviewed the progress of our knowledge of the subject of thermionics, we will now proceed to consider the application of this knowledge in the various types of thermionic valves used for the rectification, amplification, and generation of alternating currents.

II. The Fleming Oscillation Valve.

Professor J. A. Fleming in 1904 was the first to apply these phenomena of thermionics to the rectification of alternating currents, whether of high or low frequency.‡ The device which he made to effect this may take one of several forms, some of which are shown in Fig. 3. It consists of an ordinary carbon-filament incandescent lamp provided with a separate insulated electrode, in the shape of a flat or cylindrical metal plate, or another carbon filament sealed into the bulb. When the carbon filament is rendered incandescent by a source of electric current, it will be found that a single cell will pass a current through the vacuous space between the in-

* I. Langmuir: *Physical Review*, 1913, vol. 2, p. 450.

† G. S. Meikle: "The Hot Cathode Argon Gas-filled Rectifier," *General Electric Review*, 1916, vol. 19, p. 207; and *Electrical Review*, 1916, vol. 78, p. 472.

‡ See British Patent No. 24,850 1904.

sulated electrode and the hot filament, provided that the negative pole of the cell is connected to the negative side of the filament. If the connections of the cell are reversed, practically no current passes, the small amount of current obtained being due to positive ions formed from the residual gas in the bulb. This is what we should expect from the fact that the hot filament is emitting negatively charged particles, and in order to

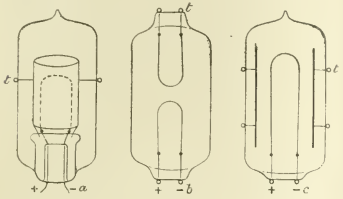


FIG. 3.

draw these across the gas space to the cold electrode the latter must be raised to a positive potential with respect to some portion of the incandescent filament.

The space between the cold and hot electrodes, therefore, possesses unilateral conductivity and the arrangement acts as an electrical valve, passing electric currents in one direction but not in the opposite direction.

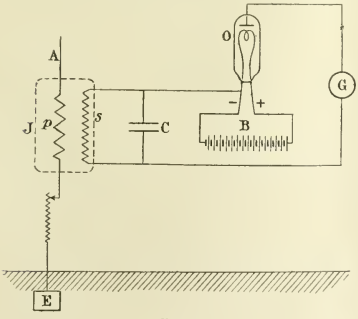


FIG. 4.

Fleming next found that this device could be used to convert electric oscillations into unidirectional currents, which may then be detected by means of an ordinary galvanometer.

The arrangement of connections for effecting this is shown in Fig. 4. The oscillation valve O has a sensitive galvanometer G placed in series with the secondary coil S, of an oscillation transformer connected between its metal plate or second electrode and the negative terminal of the carbon filament. If electric oscillations are induced in this secondary circuit by a primary coil p, then, when the carbon filament is rendered incandescent by the battery B, only one-half of the oscillatory current is allowed to pass through the gas space, viz. that in which the movement of the negative electricity is from the carbon filament to the second electrode. The galvanometer has passing through it a flow of electricity in one direction and its coil or needle will therefore be deflected.

For use as a receiver in radio-telegraphy, the primary coil p is connected in the antenna circuit between the aerial wire A and the earth connection E. The secondary circuit of the oscillation transformer is closed by a condenser C, adjusted to give resonance with the frequency of the incoming waves. The valve is connected as shown in the diagram, a telephone being inserted at G to give audible reception of signals.

The incoming electric waves excite oscillations in the antenna, which are transferred to the secondary

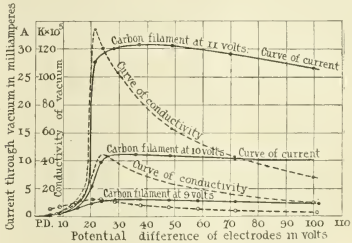


FIG. 5.

circuit S C. These oscillations are rectified by the unilateral conductivity of the vacuum valve, and each train of oscillations produces a single unidirectional rush of electricity through the telephone receiver, causing a click.

The receiver diaphragm will therefore vibrate at a frequency equal to that of the trains of oscillations received, that is, equal to the spark frequency of the wireless telegraphic transmitter from which the signals are being received. The sound heard in the receiver will therefore be a low buzzing tone or a high musical note, according to this spark frequency, and the tone will be cut up into the dots and dashes comprising the signals, as sent out by the transmitting key.

While this property of unilateral conductivity enables us to use the Fleming valve as a rectifying detector of electric oscillations, we may also make use of it in another manner, depending upon the fact that the gas space inside the bulb does not obey Ohm's law as a conductor.

If we apply a steadily increasing electromotive force between the second (cold) electrode and the filament (cathode), we find that the current does not increase uniformly, but rises fairly quickly to a maximum value

(the saturation current for the gas space), after which it falls off very slowly. Corresponding to this, the conductivity or the ratio of current to voltage in the gas space rises to a maximum and then falls off.

Fig. 5 shows the current and conductivity curves obtained by Professor Fleming for an oscillation valve with a metal cylinder surrounding the carbon filament, the latter being heated to different temperatures. The valve is more completely unilateral the colder the metal cylinder is kept, for obviously if we allow this cylinder to become heated by radiation from the filament, it will itself commence to emit ions and the current between the filament and the second electrode will not be entirely in one direction.

Now it will be seen from the current-voltage characteristics that the curvature is not constant, and we can find a point near the "knee" of the curve at which the slope of the curve on one side of the point is much greater than that on the other side. This point corresponds to a certain steady voltage applied between the plate and the filament, and a corresponding steady current flowing through the valve, and the difference in slope of the curve on the two sides of the point indi-

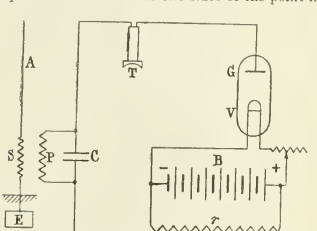


Fig. 6.

cates that if the potential difference between plate and filament be alternately increased and decreased by a small amount, the corresponding increase in current through the valve in the one case will be much greater than the decrease in current in the other case.

If this alternate increase and decrease in voltage is effected by superimposing an alternating voltage on the steady voltage, then the corresponding currents have a mean value which is greater than the current corresponding to the steady voltage alone. Hence if we have a telephone receiver in series with the valve plate circuit, under these conditions a click will be heard in the receiver every time the alternating voltage is applied to the valve electrodes.

We can therefore apply this property of the valve having a non-linear characteristic to the detection of electric oscillations, the circuit arrangements being as shown in Fig. 6. One side of the oscillation circuit PC is connected in series with a telephone T to the second electrode of the valve, whilst the other side is connected to the sliding contact on the resistance r shunting the battery B which supplies the heating current for the filament. By this means we are able to apply an adjustable steady voltage across the gas space in the valve and also, from the oscillation circuit, superimpose on this an alternating voltage of frequency equal to that of the oscillations set up in the coupled antenna circuit.

If, therefore, we adjust the slider on the resistance r so that the voltage applied to the valve corresponds to the point on the characteristic curve at which a sudden change of curvature takes place, then every time oscillations are set up in the circuit PC the effective value of the current through the telephone will be increased and a click will be heard in the receiver. Thus when the complete circuit is adjusted to receive radio-telegraphic signals, the tone heard in the receiver will be of a frequency equal to that of the trains of electric waves received, i.e. equal to the frequency of the spark at the transmitting station.

With a good valve and by carefully adjusting the conditions under which it is operating, Fleming found that this arrangement provides a more sensitive detector than that employing the unilateral conducting property of the valve.

Fleming found later that greatly improved results were obtained when the valve was constructed with a tungsten filament and an insulated copper cylinder surrounding it.* This is due to the fact that the tungsten can be raised to a much higher temperature than carbon without volatilization and gives a much greater electronic emission; and as will be seen later on in the paper, this type of thermionic valve is almost universally constructed at the present time with either a tantalum or tungsten filament.

III. The "Audion" Detector and Amplifier.

The next step in the evolution of the thermionic valve was made by Dr. Lee de Forest and consisted in the introduction of a third electrode into the evacuated bulb. Lee de Forest had been working on the simple rectifying valve containing a metal or carbon filament and one insulated electrode (already described) at practically the same time as Fleming, and his results were first described in a paper before the American Institute of Electrical Engineers in October 1906.† Considerable controversy has since then ensued as to the relative priority of the inventions of the Fleming valve and the audion, the name assigned to the valve by De Forest; but this has now been settled in favour of Fleming for the original valve, Lee de Forest having the credit of introducing another insulated electrode into the bulb, thereby transforming it from a rectifying valve into a kind of gas relay having an amplifying effect on the received oscillations.

This modification was described by De Forest in 1913 before the Institute of Radio Engineers.‡ This third electrode consists of a metal strip or wire bent into the form of a grid, and situated between the filament and the second electrode or plate, and it serves as an independent

* British Patent No. 13,518 1908.

† *Transactions of the American Institute of Electrical Engineers*, 1906, vol. 25, p. 735; and also *Electrician*, 1906, vol. 58, p. 216.

‡ *Electrician*, 1913, vol. 72, p. 285.

path by which the electric oscillations are introduced into the vacuous space within the bulb.

In studying the action of this grid we may consider the diagram given in Fig. 7, which shows a simple method of connecting up the audion for the reception of electric oscillations.

The incandescent lamp bulb contains a tantalum filament F, which is lighted by a battery B of 4–15 volts. Close to one side of, and parallel to the plane of, the filament is mounted a small rectangular nickel plate P. This plate is connected through the telephone receiver R to the positive terminal of the dry-cell battery B_2, giving from 15 to 40 volts, the negative terminal of this battery being connected to the positive side of the filament. Between the filament and the plate is mounted the third electrode G, a grid-shaped wire or perforated plate of nickel, at approximately 1/16 inch from both the plate and the filament. Leads from the condenser C_2, in series with the grid G, and the negative end of the filament are connected to the terminals of the variable condenser C_1, which is adjusted to place the circuit L S C_1 in resonance with the received oscillations induced in the coil L S.

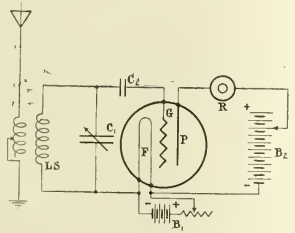


Fig. 7.

Now when no signals are being received, the grid will be practically at the same potential as the negative side of the filament, which we will regard as our zero of potential, and a certain steady current will be flowing through R in the plate circuit, the value of the current depending upon the dimensions of the valve and electrodes, the temperature of the filament, the nature and pressure of the gas, and the voltage of the battery B_2.

If now the grid be raised to a positive potential with respect to the negative end of the filament, the intensity of the electric field between G and F will be increased, and more negative ions will be drawn across this space than previously. Some of these will be drawn into the grid, giving a small current in this circuit, but the majority of them will pass through the perforations in the grid and will subsequently be attracted to the plate under the field created by the battery B_2. The net result, then, of imposing a positive potential on the grid will be to increase the current in the plate circuit, and, within certain limits, the greater the potential on the grid the greater is the increase in current.

Similar reasoning will make it evident that the effect of raising the grid to a negative potential with respect to the negative side of the filament will be to decrease the current in the plate circuit.

A typical characteristic curve for an audion valve, showing the variation of current in the plate circuit with the potential applied to the grid, is shown in Fig. 8. Normally the grid is practically at zero potential, indicated by the point P on the curve.

Now when electric oscillations are induced in the circuit L S C_1, from the receiving aerial circuit, these are rectified between the grid and the filament and accumulate a negative charge on the grid and the connected plate of the condenser C_2. This decrease of the grid potential causes a corresponding decrease in the plate current, as indicated by the above curve. As the train of oscillations dies away, the charge on the grid leaks away relatively slowly by means of the positive gaseous ions within the bulb, thus allowing the plate current to return to its normal value. This function takes place for every train of damped oscillations received, and hence the current in the telephone receiver alternately decreases and re-assumes its normal value, at a frequency equal to that of the spark at the

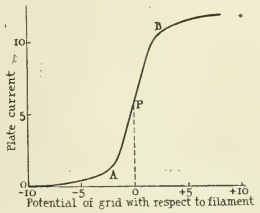


Fig. 8.

transmitting station, and the telephone diaphragm will therefore vibrate at this same, audible frequency.

This three-electrode valve may also be used as a detector without employing the grid condenser C_2. In this case the grid potential is maintained normally at one of the bends A or B of the curve in Fig. 8 by means of a separate adjustable battery. Then as the incoming oscillations cause the grid potential to vary alternately on either side of this value, the resulting changes in plate current, on account of the asymmetry of the curve, are not symmetrically alternating about the normal value but have a direct current component. Hence each train of oscillations received produces a unidirectional impulse through the telephone receiver and the diaphragm of the latter will vibrate at the spark frequency of the transmitter.

Whichever arrangement is used, the result will be the same in that a note of audible frequency will be heard in the receiver, cut up into dots and dashes in accordance with the signals sent out by the transmitting key.

The intensity of the sound depends upon the voltages

of the batteries B_1 and B_2, and the best position can be found by adjusting these while listening to the note received. When the best adjustment has been obtained it will be found that the intensity of the received signals is several times as great as those which would have been obtained by connecting the receiver directly in the receiving circuit, showing that this audion valve has acted in a true sense as an amplifier of the received signals, exerting a kind of relay action quite distinct from the simple rectifying properties of the Fleming valve. The audion, however, differs from the most perfect contact relay device in giving a quantitative response, that is to say, up to the saturation currents for the gas space within the bulb the change in plate current is approximately proportional to the grid voltage.

Lee de Forest made numerous experiments with tungsten and other filaments, with platinum coated with alkaline metals or salts, and with various gases and vapours in the bulb, but did not succeed in increasing the sensitiveness obtained with a tantalum filament and atmospheric air exhausted to the highest vacuum. He found that the best value of the battery (B_2) potential to procure the maximum sensitiveness depended upon the degree of evacuation, being roughly proportional to the same.

When the voltage of this battery B_2 is sufficiently raised, the ionic discharge from the hot filament cathode becomes visible in the form of a blue glow, occupying practically the whole bulb. A similar blue glow may be brought about in normal working if a powerful spark discharge occurs in the neighbourhood of the audion, causing a momentary large potential to be impressed upon the grid. The appearance of this blue arc is always a sign that the bulb is being over-run as regards the current passing from plate to filament. In this connection an interesting phenomenon may be observed in certain bulbs when the voltage of the battery B_2 in the plate circuit is adjusted until the blue glow is just visible round the edges of the plate. Then, when powerful impulses are received on the grid, a momentary flaring out of this blue aura can be observed with each signal, so that it is possible to read the telegraphic signals by sight.

The possibility of this blue glow effect, together with other properties due to the presence of some remanent gas in the bulb, gives rise to certain irregularities in the working of the audion, which place it at some disadvantage compared with a modified form, much more highly exhausted, to be described later. The presence of the blue glow is also very detrimental to the life of the valve, owing to the disintegration of the filament caused by the intense bombardment by the positive ions.

A great advantage which this thermionic valve amplifier has over any other relay device, is that there is no lower limit of sensitiveness; for, if the original impulse received is too minute to be directly discernible it may be amplified one or more times, and the effect of the original impulse will be observed to exist. The simplest arrangement of connecting two amplifiers in cascade to obtain increased magnification is shown in Fig. 9. A step-up transformer T_1 is provided if the original impulses coming from s are of low voltage, the secondary winding being connected across from the grid to the filament of the first valve as shown. In the plate circuit of this valve is included the primary of the transformer T_2, the secondary winding of which transfers the amplified impulses from the first valve to the grid circuit of the second. Similarly, valve No. 2 may actuate a third, and so on, the successive steps requiring as a general rule larger bulbs with larger heating areas and electrode surface to carry the increasing currents. In this manner the received signals after having been rectified to the form of impulses of audible frequency may be further amplified several times, the alternating potential applied to the grid of each valve producing synchronous amplified variations in the corresponding plate current, in accordance with the sloping part of the characteristic curve, in Fig. 8. The receiver placed in the plate circuit of the last valve will then be operated with the total amplified current obtained from the original impulse.

De Forest, making measurements of the amplification by the shunted received method, found that a good bulb gives an amplification of five times, and with three in cascade he obtained a magnification of 120 times, this including the losses in the three transformers in circuit.

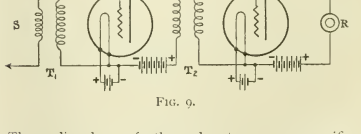


FIG. 9.

The audion has a further advantage as a magnifier in the absence of any periodic or very delicate adjustment, and also in its freedom from the effects of mechanical vibration or disturbances.

The immediate use of this valve for amplifying, and rendering readable, signals which were previously inaudible, will be obvious, giving, as it does, a greatly increased receiving range for any wireless station.

IV. The Lieben-Reisz Valve.

At about the same time that De Forest was investigating the three-electrode valve, Messrs. Lieben and Reisz were carrying out experiments in Vienna on a gas valve containing a somewhat different form of ionizer, utilizing the fact discovered by Wehnelt in 1904, that strongly heated oxides of certain metals, particularly those of calcium and barium, emit electrons at very low voltages.*

Willows and Hill described some experiments in 1911, making use of this fact to obtain increased ionic emission and sensitiveness in a modified form of Fleming valve.† They used electrodes of platinum, both of which could be heated by a current. The cathode was coated with calcium oxide (lime) which emits negative electrons on being raised to a white heat, while the anode was

* Wehnelt: *Philosophical Magazine*, 1905, vol. 10, p. 80.
† Willows and Hill: *Electrician*, 1911, vol. 68, p. 302.

covered with aluminium phosphate, which gives out positive ions when raised to a dull red heat. They found that this method gave improved rectification and greater sensitiveness than the ordinary Fleming valve.

The final form of the Lieben-Reisz valve was described by one of the inventors in 1914.* The arrangement of the connections is shown in Fig. 10.

The Wehnelt cathode K consists of a platinum strip 1 metre in length, 1 mm. wide and 0·02 mm. thick, wound in a zigzag form upon a glass support, the strip being coated with a thin layer of calcium oxide or barium oxide. The grid G is a circular aluminium plate perforated with holes about 3·5 mm. diameter, while the anode A is a short spiral of 2 mm. aluminium wire.

The three electrodes are mounted in an evacuated glass vessel of the shape illustrated, the approximate dimensions of the valve being 16 inches long by 4 inches maximum diameter.

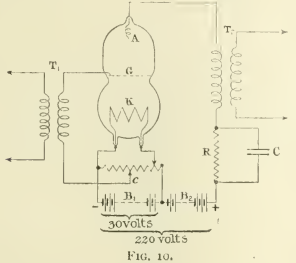


FIG. 10.

The cathode is brought to a bright-red heat at a temperature of about 1,000° C. by a battery B of about 30 volts. A certain steady voltage is impressed upon the grid from the sliding contact e on the potentiometer connected across the heating battery. The current to be magnified is led to the grid through the transformer T_1, the amplified current being drawn from the secondary of the transformer T_2. The necessary working voltage in the anode circuit is about 220, and a resistance R is included to prevent too great an increase in the discharge current, a condenser shunt being provided for the amplified alternating current.

In the early experiments it was found difficult to obtain a uniform discharge owing to the variation of the gas pressure inside the tube, this giving varying sensitiveness and entailing constant adjustment of the grid and heating voltages. It was therefore decided to replace the gas discharge by a vapour discharge, by introducing mercury vapour into the tube, constancy of pressure being obtained by keeping a small quantity of liquid mercury in a small side tube attached at the bottom of the main tube.

Actually in the final form of the valve an amalgam of mercury with a lower vapour pressure is used, as the vapour pressure of mercury rises rapidly at temperatures above 20 C., this giving rise to high current densities at the cathode sufficient to cause fusion of the platinum strip.

Although the discharge is maintained by the glowing oxide cathode, the majority of the current is carried by the mercury vapour, and thus the ageing of the tube due to the occlusion of the residual gas is very small, and a life of from 1,000 to 3,000 hours is obtained.

The inventors claim an amplification of 33 times for this type of valve, independent of the amplitude of the primary current, and that, using four such valves connected in cascade, alternating currents of frequencies ranging from 2,000 to 8,000 cycles per second have been magnified 20,000 times with perfect reproduction of the original wave-form.

This form of gas relay has been adopted by the A.E.G. and is used by the Telefunken Company as an amplifier for received radio-telegraphic signals; but it is probable that the large size of the tube and the high voltages required to operate the valve will seriously limit its field of application in spite of the high value of the magnification obtained.

V. The Pure Electron Discharge Valve.

In the types of valves already described, employing the thermionic currents obtained in an evacuated bulb, the latter always contained a certain amount of residual gas. In this respect we must state that a pressure of the order of 1/10,000 mm. of mercury indicates that a relatively large amount of residual gas is present in the bulb. This residual gas, as we have seen, had a very considerable influence on the operation of the valve in supplying positive ions within the bulb, which neutralized to a great extent the space-charge effect of the electron currents between cathode and anode, and enabled comparatively large thermionic currents to be passed under potentials of 50 volts or less. But the presence of gas to this extent within the bulb has been found to carry with it certain disadvantages. In the first place, the characteristics of the valve tend to become very irregular, the current-voltage curve often showing decided kinks at moderately high voltages. In many cases also, when working at high cathode temperatures and at high anode potentials, the discharge becomes very unstable at certain points and the characteristic for increasing voltages is somewhat different from that in the reverse direction. All these effects, moreover, vary with the composition and pressure of the contained gas, and both these vary with the intensity and duration of the discharge passing through them, the pressure decreasing considerably after a time, similarly to the manner in which an X-ray tube becomes "hard" after prolonged use. Another effect of the positive ionization within the valve is the tendency to disintegrate the cathode by the bombardment of the positive ions, and so considerably diminish the life of the valve.

Most, if not all, of these defects are absent in the pure electron discharge type of valve, which is the outcome of the investigations of Dr. Langmuir in

* Reisz: *Electrician*, 1914, vol. 72, p. 726.

the General Electric Company's Research Laboratory at Schenectady, N.Y. In this valve the evacuation of the bulb is carried out to the highest possible degree, to eliminate all possible ionization, in which case, as shown by Langmuir, the electron emission from the cathode follows Richardson's equation absolutely, and the corresponding thermionic currents can be obtained provided that sufficient voltage is applied to the anode to overcome the space-charge effect of the electron stream from the cathode.

To distinguish this type of valve from those containing some residual gas, the term "kenotron" has been applied to it. This name has since become generally applicable only to the form of the valve containing two electrodes, and used as a rectifier, the term "pliotron" having been designated to a kenotron provided with a third electrode or grid to convert it into an amplifier of alternating currents.

As an example of the first use of a kenotron, mention may be made of the X-ray tube invented by Dr. W. D. Coolidge in 1913.* In this tube the cathode is formed of a small flat spiral of tungsten wire surrounded by a cylindrical sleeve of molybdenum which serves as a focusing device, while the anode, or target, consists of a massive piece of wrought tungsten supported near the centre of the tube by a molybdenum rod. The tube is exhausted to the highest degree in the manner described below, and the vacuum is such that, unless the filament is heated, the tube shows no conductivity in either direction even with a voltage as high as 100,000. With the filament heated, the tube can be used for the production of X-rays with voltages as high as 200,000, and the intensity of the discharge can be completely controlled by varying the temperature of the cathode. The current through the tube is absolutely unidirectional owing to the absence of gas, and there is no heating of the cathode by the discharge current, and no evidence of any disintegration of the cathode. These factors enable the tube to be run continuously at a high energy input, while the intensity of the discharge remains absolutely constant. In ordinary use the temperature of the filament is so low as to prevent any appreciable evaporation or deterioration, giving the tube an almost unlimited life.

Dr. S. Dushman † has described other forms of the kenotron used for the rectification of alternating currents. These can be constructed with a thermionic current-carrying capacity up to 0·5 ampere, the filament being run at a temperature in the neighbourhood of 2,500° K., at which the life of the valve is approximately 2,000 hours. Since the characteristics of the kenotron are positive and perfectly stable, several of these instruments can be run in parallel and each one will take its proper share of the current. By this means the rectification of very large currents can be carried out. In his paper, Dushman reproduces some oscillograms which show the limitation of the thermionic current, first by the potential applied to the anode, and secondly by the temperature of the cathode. These oscillograms also show the perfect rectification obtained with this type of valve. A typical form of the kenotron for use up to 50,000 volts is illustrated in Fig. 11, the filament being mounted between two parallel plates, together forming the anode; this arrangement is used in order to balance as far as possible the electrostatic forces between the anode and the filament, which may become very great at high voltages and tend to pull out and break the filament.

The general construction and use of the pliotron, containing three electrodes, is described by Dr. Langmuir in his paper before the American Institute of Radio Engineers in April 1915 * and also in the patent †

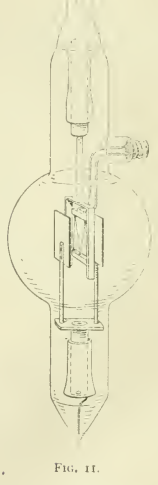


Fig. 11.

covering this invention. The general arrangement of the three elements is very similar to that employed in the De Forest audion, the details being modified according to the use for which the valve is required. The filament is of tungsten wire, and is usually either in the form of an inverted V or stretched straight between the supporting wires. The second and third electrodes are of nickel wire and plate respectively, and with the V-shaped cathode are arranged on either side of this in parallel planes as illustrated in Figs. 12 and 13. In the other form the grid is formed of a cylindrical spiral of nickel wire around the filament as axis, the plate forming a co-axial cylindrical sheath surrounding both grid and filament.

* W. D. Coolidge: *Electrician*, 1915, vol. 74, p. 505: British Patent No. 14,892, 1913.

† S. Dushman: *General Electric Review*, 1915, vol. 18, p. 156; and *Electrician*, 1915, vol. 75, p. 276.

* I. Langmuir: *General Electric Review*, 1915, vol. 18, p. 327; and *Electrician*, 1915, vol. 75, p. 240.

† British Patent No. 15,788 1914.

When these elements have been mounted in the tube the latter is evacuated by the most approved methods of electric lamp exhaust, using either the Gaede molecular air pump,* or better, the mercury condensation pump as developed by Langmuir.† The first evacuation is carried out with the whole valve heated in a

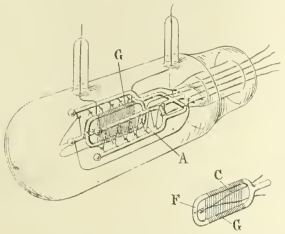


FIG. 12.

suitable furnace to the highest temperature that the glass will stand without softening, in order to remove as much as possible of the gas and vapour occluded on the walls of the vessel. It is desirable too that all the electrodes should be heated electrically if possible, to a temperature of about 2,500° C. But this heating

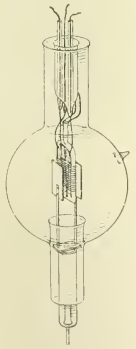


FIG. 13.

alone will not remove all the gas, and the first electron discharge to which the tube is subjected will liberate a considerable amount of gas from the surface of the metal. To complete the evacuation to the required degree, the pump is maintained continuously operated while the tube is subjected to an electron discharge between cathode and anode at a voltage which is gradually increased to a value somewhat greater than the normal working voltage of the valve. Care must be taken at the commencement of this operation not to use a voltage sufficient to cause the blue glow effect which will result in disintegration of the cathode; but towards the end of the operation the electronic bombardment of the anode must be very intense in order

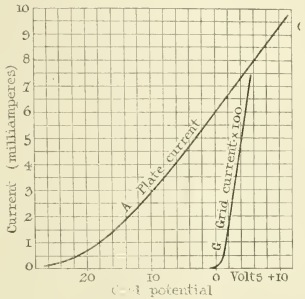


FIG. 14.

completely to free the metal electrodes from occluded gas.

By this means the bulb is exhausted down to a pressure of the order of 1/100,000 mm. of mercury, and no deterioration of this vacuum takes place during the normal operation of the valve.

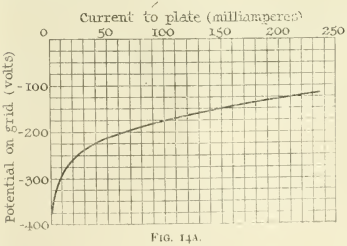


FIG. 14A.

As has been previously pointed out, the characteristics of this type of valve are perfectly smooth and regular, and quite free from all the disturbances and points of instability which often accompany the other types of gas-filled valves. The characteristics of the pliotron depend upon the length of filament used, the distance between filament and grid, the spacing between the grid wires, the diameter of the grid wires, the distance between grid and anode, and the size and shape of the

* *Engineering*, 1913, vol. 96, p. 379.
† *Electrical Review*, 1917, vol. 80, p. 41.

anode. The important characteristics of a pliotron to be observed are, first, the variation of the current flowing between the anode and cathode with the potential on the anode and with that on the grid; and second, the variation of the current flowing to the grid with the same potentials of anode and grid.

The characteristics of a pliotron of the type shown in Fig. 12 are shown in Fig. 13, the curves showing the variation of the current flowing to the plate and grid as the voltage on the grid is varied, while the anode potential is maintained constant at 220 volts. For different potentials applied to the anode, these curves are shifted vertically, by amounts proportional to the change in anode potential. Dr. Langmuir has found that these curves can be approximately represented by the formula

$$i = A\,(V_a + k\,V_g)^{3/2},$$

where i = current flowing to the anode,
V_a = voltage on the anode,
V_g = voltage on the grid.
and k and A constants which depend upon the dimensions of the valve and the relative shapes and positions of the electrodes.

In order to pass through the vacuum the currents at which this type of valve normally operates, the potentials which must be applied to the anode are considerably greater than those used in the case of the audion, but if it is necessary the pressure may be increased up to several thousand volts without any evidence of positive ionization such as the blue glow effect being observed.

Owing to the extensive commercial use of thermionic valves for various purposes at the present time, there is naturally considerable development and improvement continually going on, but it may safely be said that all the valves in use belong in principle to one or other of the types described above. A review by Dr. W. H. Eccles of the recent patents applied for on this class of apparatus, shows that the chief improvements which have been made are slight modifications in the arrangement of the electrodes and also alterations in the operating circuits to obtain increased sensitiveness.*

VI. The Use of the Thermionic Valve as a Rectifier, Amplifier, and as a Generator of Alternating Currents.

As it is not the object of the present paper to describe in detail the various circuit arrangements and their mode of operation, brief mention only will be made in conclusion of the more immediate applications of thermionic valves. For further details concerning the practical operation of these, reference may be made to some recent articles in the *Wireless World*,† and also to a paper read before the Institute of Radio Engineers by E. H. Armstrong in 1916.‡

The manner in which these valves may be used as detectors and rectifiers of electric oscillations for use in radio-telegraphic receiving stations, has already been described in connection with the Fleming valve and De Forest audion. The pliotron may be used in an exactly similar manner to the audion, except that if it is attempted to use a condenser in series with the grid as shown in Fig. 7 it will be found necessary to shunt the condenser with a high resistance and often to place a battery of a few volts' pressure in series with the resistance to prevent the accumulation of a large negative charge on the grid.

An interesting discovery was made by Mr. W. C. White of the General Electric Company's Research Laboratory, on the effect of a very minute trace of certain gases introduced into a pliotron valve which

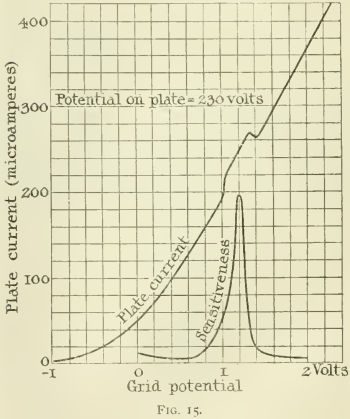


Fig. 15.

greatly increases the sensitiveness of the device as a detector.* To produce the desired pressure in the tube and maintain this constant, he used the vapour from a small quantity of silver amalgam placed in the tube. The quantity of gas in the tube is very much less than that in the audion and there is no evidence of positive gas ionization. In this condition, the characteristics of the tube show a kink, as in Fig. 15, indicating a region of instability for a certain value of the grid potential, and in this condition the sensitiveness of the detector is very high. The explanation of this phenomenon is rather obscure.

In 1916 an account was given by Mr G. S. Meikle, of the use of thermionic rectifiers for charging batteries at central stations.† For this purpose it is inconvenient to use the kenotron type of valve, owing to the

* W. H. Eccles : *Electrician*, 1916, vol. 77, pp. 571 and 594.
† *Wireless World*, 1917, vol. 5, pp. 158, 230, 236, 439, 594, 662.
‡ E. H. Armstrong : *Electrician*, 1916, vol. 76, p. 798.

* See footnotes on page 262.
† G. S. Meikle : *Electrical Review*, 1916, vol. 78, p. 472.

high voltages necessary for its operation. Consequently a gas-filled rectifier is used, and it was found in the course of its development that the introduction of pure argon into a kenotron tube at a pressure of from 3 to 8 cm. of mercury, while being quite effective in supplying positive ions to neutralize the space-charge effect, had no influence on the thermionic emission from the tungsten cathode and caused no serious disintegration of the latter. Valves on this principle may be designed to rectify currents of from a few milliamperes up to several amperes, at potentials of from two or three up to several thousand volts.

A further description of this commercial type of argon-filled rectifier, with a charging capacity of from 2 to 6 amperes, was given recently by R. E. Russell, who designates this valve by the term "Tungar Rectifier." *

The use of the three-electrode type of valve as an amplifier of the small electric oscillations occurring in

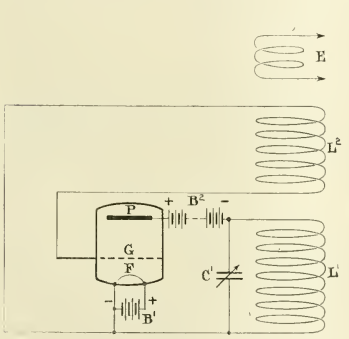


FIG. 16.

the receiving circuits of a radio-telegraph station were described above in the sections dealing with the audion and the Lieben-Reisz valve. This amplification may be carried out in either the radio-frequency or audio-frequency circuits or in both, as desired, since the operation of all the types of thermionic valves described is independent of the frequency of the currents used.

For this reason the valves may be employed for the amplification of speech currents in ordinary wire telephony, where it is desired to extend the range of speech transmission, or where the line is already so long that the attenuated currents are not sufficient to give an audible sound when the receiver is connected direct. In introducing an amplifier in this manner, the leads previously connected to the receiver are connected between the grid and the filament, the receiver being either transferred to the plate circuit or connected to the secondary of a transformer, the primary of which is connected in the plate circuit. Several valves may be connected in cascade as described in connection with the audion, in order to obtain increased amplification.

Thermionic-valve relays were used for the amplification of speech currents on this principle in the recent long-distance telephone tests between New York and San Francisco, a distance of 5,000 kilometres. Similar and more recent use of these valves as telephone relays on the line between Paris and Marseilles has shown that this application can effect a considerable saving in the amount of copper which must be used in the laying of trunk telephone lines.

The property of the three-electrode thermionic valve of amplifying small alternating currents enables it to be used as a generator of electric oscillations with but a slight modification of the circuit arrangements. Instead of the alternating potential being supplied from an external source, it is supplied from one winding, L_2, of a transformer, the other winding, L_1, of which is connected in the plate circuit as shown in Fig. 16.

If we apply a small oscillatory potential difference to the grid circuit, a magnified oscillation will result in the plate circuit. If the transformer connections are correct this increased current in the plate circuit will induce a further increased potential variation in the grid circuit. This will result in a further increased current in the plate circuit, and so the two circuits will continue to react on each other, and the amplitude of the oscillations in the plate circuit will continue to increase, until the whole system settles down to a steady state. By this means fairly powerful oscillations may be set up, depending upon the size of valve used, and by means of a third coil, E, coupled to the transformer, the generated alternating current may be tapped off and used for any purpose required.

The frequency of the oscillations is determined by the dimensions of the self-induction L_1 and capacity C_1 in the plate circuit, and by varying these the frequency may be altered within wide limits. Mr. W. C. White * has described experiments in which a pliotron was made to give oscillations at the extreme frequencies of one-half period per second, and 50 million periods per second.

The thermionic valve in this way provides a very convenient generator of perfectly steady, pure sine-wave alternating current, the frequency of which may be varied at will. The currents can be obtained of almost any desired amplitude by using a valve of suitable dimensions and characteristics. Pliotrons can be constructed with an output of 1 kilowatt, and greater powers than this can be easily obtained by connecting several of them in parallel. Used in this manner the thermionic valve would appear to provide an ideal generator of continuous oscillations for use in both radio-telegraphy and radio-telephony. In this application it is noteworthy to remark that some 300 to 500 of such oscillating valves were used in the successful long-distance wireless speech tests carried out in 1916 between Arlington, U.S.A., and the Eiffel Tower, and

* R. E. RUSSELL: *General Electric Review*, 1917, vol. 20, p. 209.

* W. C. WHITE: *General Electric Review*, 1916, vol. 19, p. 771

between Arlington and Honolulu, a distance of 5,000 miles.*

The smaller form of the oscillating valve has also provided a very simple form of detector for use in continuous-wave radio-telegraphy on the heterodyne principle The valve receiver is arranged to generate local oscillations of a frequency somewhere in the neighbourhood of those arising from the incoming signals. Those two frequencies, both too high to be audible themselves, are made to interfere, producing beats of a frequency equal to the difference of the two original frequencies, and audible in the telephone receiver as a musical note.

* P. R. COURSEY: *Wireless World*, 1916, vol. 4, p. 220

PROCEEDINGS OF THE INSTITUTION.

602ND ORDINARY MEETING, 6 DECEMBER, 1917.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 22nd November, 1917, were taken as read, and were confirmed and signed.

A paper by Mr. W. A. Gillott, entitled "Electrical Cooking as Applied to Large Kitchens" (see page 92) was read and discussed, and the meeting adjourned at 8 p.m.

603RD ORDINARY MEETING, 13 DECEMBER, 1917.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 6th December, 1917, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

A paper by Mr. A. J. Stubbs, entitled "A Case for the Adoption of the Metric System (and Decimal Coinage) by Great Britain" (see page 129) and one by Mr. L. B. Atkinson entitled "The 'Pros and Cons' of the Metric System" (see page 121) were read and discussed, and the meeting adjourned at 8.15 p.m.

604TH ORDINARY MEETING, 10 JANUARY, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 13th December, 1917, were taken as read, and were confirmed and signed.

Messrs. J. H. Jenkins and H. Brazil were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

Tough, George. Turner, Edgar Percival.
Wallace, John Napier.

Associate Members.

Bircham, Francis Richard S.
Colley, Leo Joseph St. John, Major R.E.
Coombes Frederick George.
Cope, Ernest Frank.
Hiscox, Herbert Augustus.
Osborn, Stanley.
Owen, Alexander Cay.
Phillips, John Charles.

Associates.

Finch, Arthur Leighton.
Gee, Harry Thomas Page.

Graduates.

Adams, Herbert.
Annear, Joseph Charles, Capt. R.E.
de Macedo, Joao Buarque.
Feil, Walter Charles.
Garrett, Henry Ralph, 2nd Lieut. R.E. (T.).
Hands, William Edward.
Harris, Henry Kingsford, M.A.
Helliwell, Alfred.
Hughes, Llewelyn.
Meade, John Henry.
Rickets, William John.
Smith, Walter Sydney B.

Students.

Ablett, Clifford Beresford.
Balbi, Charles Mackenzie R.
Barrington, Reginald Jack C.
Beltran, Felipe.
Bhavnani, Krishna Dayaram.
Birch, Harold.
Boyce, Pheroze Merwanjee.
Brandao, Manuel Francisco de Almeida.
Clark, Robert Cyril Leslie.
Collard, John.
Coote, Charles D.
Corner, Herbert.
de Arevalo, George Gil.
Dunster, Basil Newport.
Edwards, Percy Lancefield.
Emsley, Frank.
Figueira, Alvaro Lopes.
Garwood, Godfrey Thomas.
Griffiths, Leonard.
Ibeson, Willie.
Kendall, Reginald George Gunton.
Kennedy, John Gilbert.
Klein, Philip.
Leckie, Robert Vyvian.
Leckie, Walter Francis.
Leclezio, Maurice Jacques Leon.
Levinson, Charles.
Lopez, Charles.
Martinez, Delfin.
Maynard, William M.
Rait, Donald McCulloch.
Reyner, John Hereward.
Rix, Gordon Arthur.
Rosen, Abel.
Seelig, Bernard S.
Smith, Robert Henry.
Snipe, Norman Victor.
Watling, Wilfred Harry.
Watson, Edward Percy.

TRANSFERS.

Associate Member to Member.

Dennis, Thomas Hubert.
Morphy, Brian Harold.
Robertson, George Macaulay.
Wightwick, Humphrey Guest.

Associate to Member.

Singh, Baba Sundar.

Graduate to Associate Member.

Bathiboi, Jal Rustomjee.
Cross, Harry, Capt. A.F.F.

Student to Associate Member.

Barlow, Edwin.
Constantine, Herman Richard, M.Sc. Tech. (S.).
Henniker, Harry Vincent.
John, William James.
Lee, Henry Boswell.
Pearce, James George, B.Sc.
Robinson, Reginald Hesslewood.
Trontet, Florentin.

Student to Graduate.

Berry, Herbert.
Champ, Guy Henry.
Dowerah, Bidyananda.
Gilbert, Herbert Williams.
Gillett, Basil Montgomery.
Harvey, Ranald John.
Narayan, M. B. Tirn, B.A.
Skevington, Francis Kerr.
Sleigh, Charles Crofton.
Stevens, Percy Edward.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : H. Alabaster, P. F. Allan, J. F. Avila, A. Castello-Sosa, J. D. Dallas, L. H. Euler, S. Evershed, Captain R. Grierson, Messrs. W. T. Henley's Telegraph Works Co., Ltd., D. Henriques, H. Hirst, H. F. A. Kiner, H. W. Kolle, W. Mead, W. M. Morrison, Bt.-Lt.-Colonel W. A. J. O'Meara, C.M.G., H. Parry, C. C. Paterson, G. S. Rani, W. R. Rawlings, W. H. Scott, E. Seddon, W. W. Thomas, T. C. T. Walrond, H. D. Wilkinson, C. H. Wordingham, and W. Young.

Building Fund : H. B. Jackson, M. McGeoch, Prof. J. T. MacGregor-Morris.

The President announced [see *Institution Notes*, No. 3, page 10] that arrangements would be made to hold an informal dinner at the Waterloo Tavern, Haymarket, after each meeting if a sufficient number of members were in favour of the idea.

In the unavoidable absence of the author, Mr. C. M. Jacobs, on account of the death of his wife, a paper entitled "Electrical Control and Signalling on Railways" (see page 136) was read on his behalf by Mr. J. Sayers and discussed.

A vote of condolence was passed with Mr. C. M. Jacobs on the loss of his wife, the members rising in silence to signify their assent.

The meeting adjourned at 7.50 p.m.

605TH ORDINARY MEETING, 24 JANUARY, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 10th January, 1918, were taken as read, and were confirmed and signed.

The President having referred [see *Institution Notes*, No. 4, page 14] to the death of Sir John Wolfe Barry, K.C.B., F.R.S., a vote of condolence was passed with Lady Barry, the members standing in silence.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

A paper by Mr. F. G. C. Baldwin, Associate Member, entitled "Telephone Exchange Transfers and their Organization" was read and discussed, and the meeting adjourned at 8 p.m.

606TH ORDINARY MEETING, 7 FEBRUARY, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 24th January, 1918, were taken as read, and were confirmed and signed.

Messrs. W. Green and F. Williams were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows :—

ELECTIONS.

Members.

Gaskell, Jun., Holbrook.
Gill, Harry.
Milne, Leonard.
White, Richard Hubert.

Associate Members.

Beecher, Charles Sharpe.
Bradshaw, William Edgar.
Eastwood, Allen.
Malpass, John Bernard.
Sibree, John Oswald.
Smith, Tom.

Graduates.

Blackburn, Harry Arthur, Warrant Officer.
Collyer, John Edward E.
Cope, Frederick.
Lebedeff-Lessin, Michael Stanley.
Mackintosh, William John.
Radforth, Walter Ernest.

Students.

Batty, John.
Broughall, John Alan.
de Aguiar, John.
Dearden, David Sutcliffe.
Field, Harold Victor.
Hesketh, John Hinnell.
Hipwell, James Henry.
Homersham, Ernest Charles.
Lloyd, Thomas Harry.
Novaes, Paulo de Oliveira.
Spicer, Horace Henry.
Walker, Albert.
Wheeler, Geoffrey.

TRANSFERS.

Associate Member to Member.

Craven, George Frederick.
Davis, Vyvyan Oswald I.
Midgley, Albert Henry.
Nelson, George Horatio.
Restler, James Douglas K.
Webber, Harry.

Associate to Member.

Leggat, John.

Student to Associate Member.

Barnard, Lionel Edward.
Labayen, Alberto Villanueva y.
Lion, Bernard Samuel, B.Sc. (Eng.).
Matthews, Leonard John
Paul, Robert Buchanan.

Student to Associate.

Munro, Harold Neville.

Student to Graduate.

Beaton, Frederick George.
Davis, Vernon Lionel Frederic.
France, William George.
Goodall, John Melville.
Lawrence, Frank Hamer.

The President announced that an informal dinner would be held at the Waterloo Tavern, Haymarket, after the meeting.

Professor Magnus Maclean, D.Sc., Member, then delivered the Ninth Kelvin Lecture, entitled "Kelvin as a Teacher" (see page 169).

A vote of thanks to the lecturer was proposed by the President and carried with acclamation.

The meeting adjourned at 7.5 p.m.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 56. MAY, 1918. No. 274.

THE CONTROL OF LARGE AMOUNTS OF POWER.

By E. B. Wedmore, Member.

(*Paper first received* 16 *November*, 1917, *and in final form* 2 *February*, 1918; *read before* The Institution 7 *March*, *before the* Western Local Section 11 *March*, *before the* Manchester Local Section 12 *March*, *before the* Birmingham Local Section 20 *March*, *before the* Newcastle Local Section 8 *April*, *and before the* Scottish Local Section 9 *April*, 1918.)

Contents.

I. Introduction.
II. Prospective developments.
III. Limitation of disturbances.
IV. Limitation by sectionalizing and by employment of reactance.
Schedule of methods of employing reactance.
V. Limitation by generator reactance.
VI. Limitation by feeder reactance.
Limitation of voltage disturbance.
Use of feeder group reactances.
VII. Limitation by busbar reactances.
Sectionalizing the distribution system.
Current-limiting effect.
Provision of spare machines.
Transfer of power.
Results obtainable.
Protection of live load on sound sections.
VIII. Improvement of power factor.
IX. Interconnection of stations.
Limitations affecting parallel running.
X. Influence of live load on the short-circuit current.
XI. Limiting effect of fault resistance.
XII. Limiting disturbance by the use of protective relays and the like.

Appendixes.

I. Rupturing capacity of oil switches.
II. Rating of reactances.
III. Arrangement of busbars.
IV. Current-limiting by the use of busbar reactance.
V. Transfer of load through reactances.
VI. Design of current-limiting reactances
VII. Heating and stresses due to heavy currents.

I. Introduction.

The increasing use of electrical energy and its economical production require the use of larger generating stations and the linking together of existing plants. These extensions involve something more than the use of larger units and the adding of unit to unit. New conditions are reached. Factors which were negligible in smaller aggregations of plant become serious and limiting features.

The forces accompanying a disturbance are increased, and the total number of disturbances to which a system is subjected increases automatically with each extension; thus there are introduced new problems in the design of individual parts of the plant and in the arrangement of them.

There are no insurmountable difficulties in the design of larger machines, heavier cables, and of switchgear all able to cope with larger forces than have yet been met with, but a little consideration will show that the limiting features are to be looked for not only in the generating station but in the distributing system. Stations and networks spread over a large area may be coupled together without necessarily seriously modifying the forces to be dealt with at any point, but a striking characteristic of developments now in prospect in the principal industrial areas is the increased concentration of large amounts of power in small areas. This inevitably follows the extended use of electricity for domestic purposes as well as for power production, and introduces new conditions not yet fully recognized.

One may double the size of a generating station with advantages in economy and without excessive expenditure on switchgear to take care of the conditions in the station itself; but for every machine, switch, and conductor in the main station there are large numbers of smaller machines, switches, and conductors in the distribution system, and if these also are subjected to increased forces a very heavy expenditure may be necessary to ensure satisfactory service. Not only is this true as applied to an individual town, but similar conditions may arise where a large bulk-supply scheme is devised and a number of existing small plants are linked up to a common and larger source.

It is therefore very necessary to give full consideration

to the new conditions introduced, and in this paper an attempt is made to anticipate the probable developments of the immediate future, and to show how the conditions arising may be dealt with.

The problem of maintaining continuity of supply and of protecting the plant is found to require for its solution the proper proportioning of the impedance of the different parts of the system.

There are also a number of practical details to be considered in the design and arrangement of the distribution apparatus and of the feeder system.

The employment of current-limiting reactances has been already dealt with in a paper by Messrs. Faye-Hansen and Peck,* but the subject has been treated afresh with the object of ascertaining the limiting features in the practical applications of reactance and presenting them in a form for immediate use.

II. Prospective Developments.

It is not by examination of designers' data that we can predict future developments, because in so far as details of existing practice are good we can find reason why they should not be changed. We have, rather, to examine changes in conditions. Not the least of these in this case is a general improvement in statecraft which justifies us in anticipating a more rapid development of electrical business.

Engineers have long since anticipated the possibilities of big developments in the use of electric power, and in its more economical production and distribution. The use of electricity in metallurgical and chemical processes is opening up a new field, but apart from new outlets there is scope all over the country for manifold extensions in the use of electricity for domestic and general industrial purposes.

The whole subject has been brought into public notice through the forcible representations of the Coal Conservation Sub-Committee of the Reconstruction Committee in their recent Report on Electric Power Supply in Great Britain (Cd. 8880, dated 7th December, 1917).

In this report the design and use of alternating-current generators in units up to 50,000 h.p. and over have been discussed. In this country machines are already building in sizes up to 40,000 k.v.a., and larger sizes are building in the United States.

Stations have been laid down for an ultimate output exceeding 200,000 k.v.a., and this figure has been approached in installations already in operation.

It is thought that in this country for some years to come the requirements will be met with stations not greatly exceeding 100,000 k.v.a., and mostly with generating units not exceeding 20,000 to 30,000-k.v.a. maximum rating.

It is not only the difficulties of water supply that tend to limit the size of stations, but in areas within which 200,000 k.v.a. can be utilized there will generally be economy in distribution by the employment of two 100,000-k.v.a. stations, it being under suitable conditions more economical to transport coal and water than to transmit electricity.

In neighbourhoods requiring several large interconnected stations, units above 30,000 k.v.a. can be employed economically.

In some districts there may be several such stations widely separated but interconnected, whilst in others where the demand is less or where the facilities for cheap power production are concentrated in small areas, one or more large stations situated near together may supply a wide area of high-voltage distribution. Waste-heat plants and other local economical sources of power will be utilized by connecting these to the distribution system.

In this paper the station with 100,000-k.v.a. output is taken as typical, but consideration is also given to the linking together of such stations, and of smaller sources of power such as waste-heat stations and existing generating stations of limited capacity.

As for the size of generating units, it will be seen in what follows that the general use of generator units of the order of 50,000-k.v.a. output would throw excessive stresses on distribution apparatus and small plant generally unless special precautions are taken. There are, however, other considerations also which point to the use of smaller units.

In the first place the question of spare plant has to be considered. We have to consider that a large unit may fail at a time when another similar unit is temporarily out of commission, pointing to the provision of two spares of the largest size.* This is increasingly important on large systems where more and more services become dependent upon the electric supply, and where the load factor is high. The time required to restore to service units of this magnitude that may have been put out of commission is much greater than in the case of units with which most of us are familiar.

This and the fact that such large units could not be employed economically except on large interconnected systems with a total output greatly exceeding 100,000 k.v.a., all supports the contention for the general use of machines of 20,000 to 30,000 k.v.a.

These machines, generating at about 6,000 volts, will be used mostly with transformers stepping up to 20,000 or 30,000 volts for transmission. Generally the machine and transformer bank will form one unit, all switching being carried out on the high-voltage side. There is likely to be an increasing use of overhead lines for distribution of small amounts of power over large areas, but large amounts of power will be distributed through underground cables, on account both of increased freedom from disturbance and of convenience in negotiating densely populated areas.

III. Limitation of Disturbances.

Means must be found to ensure maintenance of voltage at all parts of the system and to prevent the disturbance of running machinery.

Means must also be found to limit the power which can

* K. M. FAYE-HANSEN and J. S. PECK: "Current-limiting Reactances on Large Power Systems," *Journal I.E.E.*, 1914, vol. 52, p. 511.

* This limit of two spares of the largest size is not quite accurate, however, as if we provide an equivalent in smaller machines the cost is reduced. Thus with a 50,000 k.v.a. unit and three spares of 25,000 k.v.a any two machines can be shut down and leave not less than 50,000 k.v.a. available. The larger set will be available most of the time, so that the slight loss of economy during the short period when it is replaced by two smaller machines is negligible.

be concentrated at any point on a fault occurring, and to a figure not calling for excessive expenditure in the construction of individual pieces of apparatus.

That special steps are necessary will be abundantly clear when it is stated that if practice hitherto prevailing is followed in the extension of existing plants, switchgear on consumers' premises may be subjected to forces comparable with those now met with in large generating stations.* The rupturing capacity of oil switches is dealt with in Appendix I.

By suitably proportioning the impedance of the different parts of the system, and by the employment of quick-acting selective protective apparatus, we can, however, both limit and localize these disturbances.

IV. Limitation by Sectionalizing and the Employment of Reactance.

By the crude method of sectionalizing the plant we reduce the conditions to what they would be on small plants, and this has been done extensively. The object, however, of large combinations of generating plant is economy in production, and this is obtained by an interchange of energy between the different sections, which enables larger and more economical units to be employed, reduces the number of spare machines necessary, and improves the load factor. Thus it is interchange of power we have to provide for.

On a large plant we can to a considerable extent regain the easier conditions of small plants by dividing the system into sections and paralleling these through reactances. This will admit of the interchange of energy for purposes of economy, and at the same time limit both the interchange of energy during severe faults and the disturbance of sound sections.

The employment of reactances for interconnecting, whether between busbar sections in an individual station, in trunk mains between busbars in different stations, or in interconnectors between adjacent parts of the distributing system, has the distinctive merit that, so placed, they carry only that portion of the load being transferred from section to section, and thus waste a minimum of energy and do not interfere with regulation.

Reactance may also be employed in series in any part of the system, but, so used, the reactance will have to carry the total load fed to that part.

Wherever employed the reactance limits the disturbance in all parts of the system beyond it and tends to isolate the disturbance from all parts nearer to the source of supply.

The desired results will be most economically obtained when interconnecting reactances are employed, but if the inherent reactance of the circuits, transformers, etc., is insufficient adequately to localize the disturbance, the employment of a certain amount of artificial reactance in series will also be necessary.

The different methods of employing reactance with their advantages and disadvantages are set forth in the Schedule given on page 272.

The conclusions in the Schedule are now to be explained and illustrated.

In discussing the use of reactance it is found convenient to rate the reactance in terms of the percentage reactive voltage-drop it will give on the full-load rating of the part of the plant with which it is associated. Just as we speak, for example, of a transformer having a reactance of 4 per cent, so we speak of a busbar section reactance of 10 per cent based on the current rating of the section. This rating of reactances is considered further in Appendix II.

In this paper the rated current is assumed throughout to be "maximum rating," as recommended by the British Engineering Standards Committee.

The design of current-limiting reactances is dealt with in Appendix VII.

V. Limitation by Generator Reactance.

Reactance may be employed at the source, viz. in or with the generators themselves, where it need not interfere with the losses. It is anticipated that this method will be carried further than it has been hitherto.*

Most generating sets will be used in conjunction with step-up transformers, the machine and transformer forming one unit. In this case the transformer reactance will be additional to that in the machine and will add, say, 4 per cent, but there is no reason why the transformer should not be designed to give more than this, and at a lower cost than that of employing a separate external reactance.

* Let us assume a generating station of 100,000-k.v.a. output feeding a large town by stepping up to 20,000 volts and transmitting 20,000 k.v.a. to each of five centres at a distance of about 3 miles. The generators and step-up transformers may be taken to have 14 to 15 % short-circuit reactance; thus there will be liberated 700,000 k.v.a. on a fault near the station. Allowing 4 % reactance in the step-down transformers, and allowing for feeder impedance, there will be 200,000 to 350,000 k.v.a. liberated on a fault on the busbars at a distributing centre according to whether or not these centres are interconnected.

If now the pressure is stepped down to 6,000 volts for distribution through 0·1 sq. in. feeders a mile long, the additional impedance of individual feeders will not limit the energy liberated even at the remote end to below 50,000 to 60,000 k.v.a., and this figure may be doubled by feeders in parallel. Thus not only will all switches on consumers' premises within a mile radius have to meet these severe conditions, but all conductors or pieces of apparatus will be subjected to the corresponding mechanical forces and heating effects.

It must be remembered too that these figures of 50,000 to 60,000 k.v.a. represent values which will not be materially reduced before the switches open, even though delayed as much as a second, as the generating plant is much better able to maintain this output than it can the heavier short-circuit currents met with close to the source of supply (see Fig. 1).

If the plant was originally a small one supplying at 6,000 volts and were to be extended to the same capacity of 100,000-k.v.a. output, there would not be the limiting effect of the step-up transformers, and the maximum short-circuit near the source would be 1,000,000 k.v.a., and at the end of parallel 0·1 sq. in. feeders one mile from the distributing centres 150,000 k.v.a.

This figure is about 7 times what commercial switchgear on consumers' premises will withstand without support. It would raise the temperature of the feeder conductor at the rate of 70 degrees C. per second, and this fault in an individual consumer's premises would pull down the voltage throughout the whole system.

* It is quite feasible to build machines economically with much larger internal reactance than has been common practice hitherto. The inherent regulation will not be so good, but the normal load fluctuations on large plants with large machines are relatively slow, so that no difficulty arises in practice.

Some of the reactance may be external to the machine. Whether the reactance be internal or external the busbar voltage is maintained by hand or automatic control of the field.

An external reactance serves to limit the short-circuit current which can flow into a faulty machine, but this provision should not be necessary. After provision has been made on a large system for the proper protection of supply and of the plant generally, it will be found that the generator will not be subjected to excessive forces. From this standpoint it is better to put the reactance into the machine.

There is a practical limit to the extent to which satisfaction can be obtained by the use of generator reactance, and that arises from the fact that reactance in this position serves only to reduce the magnitude of the short-circuit currents and does nothing towards maintaining the supply voltage in the rest of the system in the event of loss of voltage by a fault at a point. In order to maintain the supply voltage, we must employ a proper ratio of busbar reactance to generator reactance and of feeder reactance to generator reactance; and as it will be found that the amount of busbar or feeder reactance which can be used is limited on account of interference with regulation, it follows that the generator reactance is also limited if a proper ratio is to be maintained between the two.

We are concerned with the magnitude of the rush of current which follows the development of a fault. The heavy current demagnetizes the field and reduces the current values, as indicated in Fig. 1, but at the first instant the field is sustained by eddy currents set up in the magnetic circuit, and the current is limited solely by the reactance of the windings.

VI. Limitation by Feeder Reactance.

The employment of artificial reactance in series with the load leads in any case to waste of energy and impaired regulation, and is therefore to be sanctioned only where no better solution is available.

Resistance and reactance in an individual feeder anywhere in the system affect disturbances in the following manner:—

(1) The feeder impedance helps to maintain the voltage on all parts of the system connected on the source side of the impedance.

(2) The feeder impedance assists in limiting the magnitude of the fault current at any point beyond the impedance.

(3) The voltage at all points beyond the impedance is equally disturbed.

If artificial reactance is to be employed, functions (1) and (3) call for the reactance to be located as near as possible to the point to be protected, whilst function (2) calls for the reactance to be located as near as possible to the source of supply.

SCHEDULE.

Control of Large Amounts of Power by the Use of Reactance.

Requirements.

To limit the area affected by a disturbance at any point.
To limit the power concentrated at any point on a fault occurring.

Characteristic.

Wherever employed, reactance limits disturbance in all parts of the system beyond it, and tends to isolate disturbance from all parts nearer to the source of supply.

Means.

A. *Utilization of inherent reactance.*—Advantages: Saves cost of special reactances and does not add to resistance and consequent losses.
Limitations: Where the load is at all concentrated, cannot be carried far enough for economical reasons.

B. *Utilization of artificial reactance.*—Advantages: Can be located where most effective.
Limitations: Must not interfere with regulation.

Method of Employing Reactance in General.

I. *Reactance in series.*—Advantages: Easy to apply.
Limitations: Carries total load fed to part protected.

II. *Reactance in parallel.*—(Sectionalizing or interconnecting) Advantages: Carries only portion of load transferred. Wastes less energy. Interferes less with voltage regulation.
Limitations: Requires sectionalizing of distributing system. Is not sufficient alone if good regulation maintained.

Methods of Employing Reactance in Series.

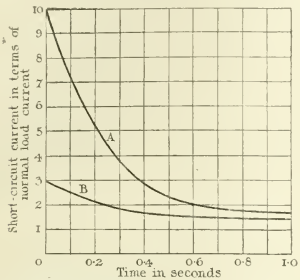
(*a*) *In generator.*—Advantages: Cheaper. Does not hinder voltage control under normal conditions.
Limitations: Considerations of design of machine. Must not swamp isolating effect of busbar and feeder reactances.

(*b*) *Added to generator.*—Advantages: Limits current which can flow into faulty machine.
Limitations: Increased cost and space required. Must not swamp isolating effect of busbar and feeder reactances.

(*c*) *In feeder.*—Advantages: Gives best protection to rest of system.
Limitations: Interferes most with voltage on part protected.

(*d*) *In group of feeders.*—Advantages: Minimum number of reactances required. Protects feeder switchgear.
Limitations: Involves several feeders where fault in one.

Inherent reactance may be utilized, however, in such a way as to serve all three functions, as may be seen by comparing Figs. 2 and 3. Fig. 2 shows power fed through eight feeders to two substations and distributed through 10 outgoing feeders. In Fig. 3 the same eight feeders are divided into four groups of two and there are 16 outgoing cables of smaller section.



A-Dead short-circuit
B-Short-circuit limited by reactance in circuit

FIG. 1.—Curves showing decrement of short-circuit currents in a typical generator.

It is clear that in the latter diagram we have not only increased the number of sections and thereby reduced the area affected by a given fault, but we have doubled the impedance between each substation and the main station, and greatly increased also the impedance in the outgoing feeders.* Thus by separ-

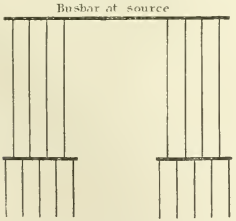


FIG. 2.—Arrangement of feeders giving low inherent impedance.

ation of feeders we can introduce more impedance both near the source and near the parts to be protected.

At the same time if the total section of copper

* From the practical standpoint, Fig. 3 may require more cables by way of spares and a larger staff of attendants, but there is an offset in that the substations may be placed nearer to the demand and the average length of the feeder reduced. Moreover, cable can be reduced by interconnecting stations if appropriate protective apparatus is employed, so that in fact subdivision can be pushed a long way without increased cost of distribution, and with great advantage from the standpoint of continuity of service.

remains the same (neglecting the slight impairment of load factor) the losses are not increased and the regulation is unaffected.

In large systems where step-up and step-down transformers are employed, these introduce further inherent reactance, so that in practice, except where there is considerable concentration of load, the use of artificial feeder reactance should be avoidable.

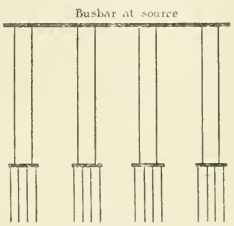


FIG. 3.—Arrangement of feeders giving high inherent impedance.

Where artificial reactance is required, it should be put as near as possible to the point to be protected. Thus in Fig. 4 reactance should be inserted at X only if it is necessary to protect the substation plant. For

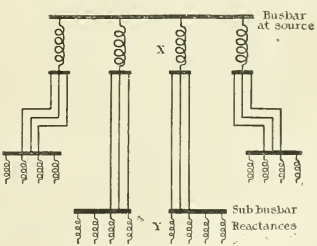


FIG. 4.—Location of feeder reactances.

the protection of consumers' apparatus position Y is the best, as this gives better voltage regulation.*

The use of series reactance interferes with the regu-

* Fig. 4 represents a distributing system with series reactance inserted at the source end and at distributing centres, in successively smaller branches of the system. We have to consider the relative merits of the two positions. The reactances at X and Y respectively carry each one-quarter and one-sixteenth of the total output. If we require to protect the individual feeders and their equipment, should we select the position X or Y? For equal protection we shall require equal ohmic value in the reactance in either position, so that the k.v.a. ratings will be proportional to the square of the current capacity. The cost of the reactances will be very roughly proportional to the square root of the k.v.a. rating, so the total cost of the reactance equipment will be of the same order for either position.

The effect on the working conditions, however, will be very different, for reactance at X will give four times the drop and waste about four times the energy in reactance at Y.

lation to an extent which may be quite serious for lighting unless the energy is transformed to continuous current. The permissible pressure drop ultimately decides the practicability of the proposition.

If the power factor of the load is 80 per cent, then the magnetizing component is 60 per cent and a 10 per cent reactance will cause a 6 per cent drop, and for other sizes pro rata.

In a case (cited in the footnote on page 271) where the inherent reactance limits the kilovolt-amperes on short-circuit to 100,000 to 150,000 k.v.a., for example, this figure can be reduced to 20,000 k.v.a., or well within reasonable limits for consumers' premises, by the employment of series feeder reactance introducing potential drops as follows on a load circuit of 80 per cent power factor:—

Load	Potential drop
1,000 k.v.a.	$2\frac{1}{2}$ per cent
2,000 ,, ...	5 ,,
5,000 ,, ...	$12\frac{1}{2}$,,

In this case the potential drop could be reduced only by improving the power factor, or by the use of less reactance and switches of larger rupturing capacity.

We shall see, however, that much better conditions can be obtained by a proper use of reactance at the generating station, in the machines, busbars, or feeders as required, to reduce the short-circuit currents at the substations.

In new large power stations it is wise to provide space for the possible addition of feeder reactance.

We conclude that inherent reactance should be utilized as far as possible, and additional artificial reactance should be used only to ensure that disturbances should be sufficiently localized and plant adequately protected against excessive stresses.

These two conditions require a similar distribution of reactance in the system, but the results obtainable from the standpoint of voltage disturbance depend upon the kind of plant employed.

Limitation of voltage disturbance.—We may consider three typical cases, viz.—

(*a*) Distribution for lighting through transformers.
(*b*) Distribution through induction motor-driven sets.
(*c*) Distribution through rotary converters and synchronous motors.

(*a*) Where the distribution is by transformer the voltage must necessarily be disturbed to an extent visibly affecting the lighting on sections adjacent to the faulty one, but the disturbance will last only until the protective gear has isolated the fault.

(*b*) *In the case of induction motors a heavy fall of voltage is not serious so long as the fault is cleared in about 2 seconds or less,* which lies well within the capacity of modern protective apparatus.

(*c*) In the case of rotary converters and synchronous motors, we have only approximate data, but can form a good general idea of what is required. A rotary converter running fully loaded will not be pulled up if the voltage falls to one-third or one-quarter of normal, but the machine is sensitive to sudden changes of phase angle. The reactance which limits the voltage drop also reduces the phase-swinging. Faults remote from the source present no difficulty, but we cannot employ sufficient reactance in outgoing feeders in the generating station to prevent the voltage being pulled down on a fault. *It is likely, however, that the machines on sound circuits will not be disturbed if the voltage does not drop below 50 per cent of normal at the source.* At the first instant the drop will be much less than this, but the generators will be quickly demagnetized and the voltage will approach the limit in less than a second.

If the generators have a short-circuit reactance of 15 per cent and are furnished with potential regulators, it is likely that they would require a feeder reactance of 33 per cent based on the generator rating to meet this condition. If now there are 10 feeders (and about the same proportion of spare feeders and spare machines), this requires at full load a feeder reactance of only 3·3 per cent based on the feeder rating. At times of light load, however, when, say, there is only one machine running, the feeder reactance would have to be proportionally higher, so that it is clearly not possible fully to protect the rotary converters all the time, even with reactances in each outgoing feeder.

It should be borne in mind, however, that in modern practice where the mid-point of the system is earthed, all faults to earth will be cleared without serious voltage disturbance, and the large majority of cable faults in particular are of this character. Moreover, the above figures apply only to the worst possible case, viz. that of faults close to the source.

There is no doubt that the conditions are further greatly improved by the employment of quick-acting switchgear able to clear a fault in one-fifth of a second or less.

Use of feeder group reactances.—A group of feeders running between two common points may be treated as a group and have a common reactance. The number of reactances may be reduced in this way and further protection given to the switchgear controlling individual feeders. The reduction in cost of reactances is partly offset by the additional cost of the necessary group busbar and group switchgear

Where feeders are grouped only at the source it is better to employ separate feeder reactances rather than group reactances, so that disturbances on any one of the sections fed shall be isolated from the others. In such a case, however, some group reactance may be employed on occasion to protect the feeder switches, as, for example, in incorporating existing feeder switchgear in a larger scheme.

VII. Limitation by Busbar Reactances.

The method of employing busbar reactances is intimately connected with the subject of the design and arrangement of the busbars themselves. This is dealt with in Appendix III. It is sufficient here to recognize that there are two distinct methods of connecting up the reactances, known respectively as the "star" and "ring" methods and illustrated in Figs. 10 and 11 respectively. It is shown in the Appendix that the star design is generally preferable after considering the operating conditions. Either system will give about

equal protection, but here again the advantage in the extreme case lies with the star design.

Sectionalizing the distribution system.—It is the system which has to be sectionalized and not the main busbars alone. Clearly the sectionalizing of the busbars is of very little value if the sections are tied solidly together outside the generating station. This requires that there shall be a correspondence between the busbar sections and the sections of the distributing system. The ultimate plan must as far as possible be pre-arranged from the commencement so that adequate provision may be made in each section of the busbar for the ultimate equipment required by the corresponding section of the distributing system.*

Current-limiting effect.—In considering what results can be obtained by the use of busbar reactance the subject of the transfer capacity required is important, because for a given voltage difference between sections the amount of current to be transferred limits the

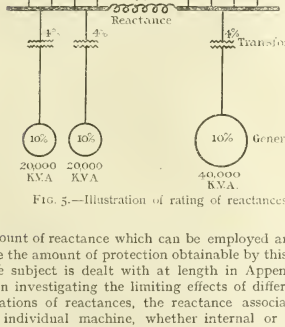


FIG. 5.—Illustration of rating of reactances.

amount of reactance which can be employed and therefore the amount of protection obtainable by this method. The subject is dealt with at length in Appendix IV.

In investigating the limiting effects of different combinations of reactances, the reactance associated with an individual machine, whether internal or external, or in the step-up transformer, is treated as one item, described as generator reactance and indicated by the letter A. The busbar reactances, however connected, are indicated by the letter B. Thus in Fig. 5 A = 14 per cent, B = 14 per cent, and B/A = 1.

* The problem as it applies to the main switchboard is simple in comparison with the problem as it applies to the distributing system. It is not possible to lay down general rules for the latter, as the requirements depend so much upon local conditions, but it is essential to have a definite plan in view and to consider each addition to the plant from the point of view of the requirements of the final scheme. It is not necessary actually to sectionalize the system from the commencement into the number of sections which will ultimately be required, but details should be arranged so as to permit of a section being divided into two when it exceeds the predetermined limit. The alternative course will result not in immediate disaster, but in a gradual lowering of the factor of safety until serious trouble points to the cause and necessitates a far more costly remedy. So far as it affects the main station switchgear the problem consists principally in arranging sufficient space for additional circuits on a section and for the ready transfer of circuits from one section to another as the system grows.

Fig. 6 gives a good idea of the results obtainable by the introduction of busbar reactances. The short-circuit current, on the assumption that no reactance is employed, is taken as unity, and the curves show how much this figure is reduced by the employment of busbar reactance. It will be seen for example that with B/A = ½ and with five busbar sections the short-circuit currents are more than halved. The results obtainable are investigated in detail in Appendix IV. From the data there given it will be seen, for example, that with five busbar sections, with generator reactance of 17 per cent and busbar reactance of 6 per cent, it is possible to keep the maximum value of the short-circuit k.v.a. down to three times the plant capacity, instead of 10 times the plant capacity, a common figure at the present day. That is, *we build a* 100,000-

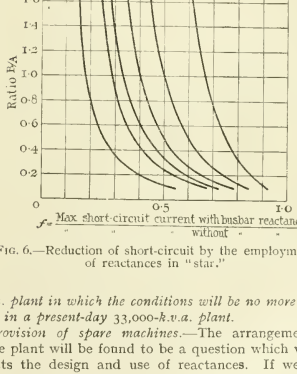


FIG. 6.—Reduction of short-circuit by the employment of reactances in "star."

k.v.a. plant in which the conditions will be no more severe than in a present-day 33,000-*k.v.a. plant.*

Provision of spare machines.—The arrangement of spare plant will be found to be a question which vitally affects the design and use of reactances. If we plan for five machines clearly we cannot employ six busbar sections, or a symmetrical arrangement of three, and if we use four the fifth machine cannot conveniently be connected up as a spare to any one section.*

The number and size of machines should preferably be determined so that with adequate provision for spares the machine capacity will de divided equally between the sections, the number of sections being such as to give the required degree of protection whilst suiting the local conditions.†

* This could be done through the auxiliary busbar, but not without involving complicated switching operations and seriously limiting the flexibility (the measure of flexibility is roughly the number of different simple ways in which one can meet usual and unusual conditions of service).

† If the machines are not uniformly distributed as to capacity amongst the sections, certain sections will give much higher short-circuit currents than others, and this cannot well be remedied by using higher reactances with these sections, as the permissible reactance is limited by other considerations.

For reasons previously given it is assumed that there will generally be two machines in excess of the total corresponding to the maximum output ; thus, of eight sections, two will be spare. There may be four busbar sections with two each, but the total maximum output will be that of six, and the total maximum output of a section that of $1\frac{1}{2}$ machines. This exercises a large influence on the reactance rating, as it limits the transfer of current necessary.

Transfer of power.—We desire to transfer power from section to section for purposes of economy, and this transfer may amount to 20 to 70 per cent of the capacity of a section. This transfer may take place in either direction. For it to take place at all it is necessary to set up a difference of potential between sections, whereas working conditions require that the sections shall be at substantially the same voltage.

The transfer of the energy component of current through the reactance will not require a potential difference greater than is necessary to overcome the ohmic resistance, and this will be some small fraction of 1 per cent, perhaps one-fifth with 10 per cent reactance between sections. To transfer magnetizing current, however, will require a relatively large potential difference, and this will be in fact the reactance drop at the current in question, and this proves to be the limiting feature.*

The obvious solution appears to be to transfer the load at a higher power factor and to make up the shortage of magnetizing current by supplying it from the machine or machines tied to the section in question.

In pushing the use of reactances up to the limit it is necessary to utilize this method of maintaining the voltage, but it is not one which should be used under daily working conditions. It involves underloading one or more of the machines, extra care in running adjustments, and in case a fault occurs on the section receiving current, the voltage drop will be greater.

Results obtainable.—The practical possibilities of this method of control are investigated in Appendix IV, and it will be found that ample protection can be obtained by the use of generator and busbar reactances under normal working conditions without resorting to transference at a power factor above that of the load ; but this method can be advantageously resorted to under emergency conditions.

As the result of this investigation it is possible to furnish a table showing results obtainable under practical working conditions, and this has been done in the Appendix.

There is a preponderance of advantage in the use of two unit machines per section, or of course the equivalent in smaller machines. If larger units are installed later than were originally contemplated, these may be of twice the size and arranged one per section with suitable reactances and without materially affecting the short-circuit factor.

As a typical example of what can be done we may take the case of five sections and two machines per section. Here with generator reactance of 15 per cent and busbar reactance of $7\frac{1}{2}$ per cent we get a short-circuit factor of 3·3 on the maximum output. That is, a station rated to give 100,000-k.v.a. output would give 333,000 k.v.a. on a fault between phases near the source.

Protection of live load on sound sections.—In considering the use of feeder reactances it has been shown that where a phase-to-phase fault occurs on the load side of the reactance, it is possible to maintain sufficient voltage on the source side of the reactance to keep rotary converters in step (see page 274, section *c*). In the example there given we have shown that the reactance should have a value of about 33 per cent based on the generator rating. Applying this to section reactances, the basis becomes that of a busbar section and the 33 per cent applies to the total reactance between sections.

From what has been said above, it is evident that the use of any such reactances would seriously limit the energy transfer that could be made with any reasonable voltage difference between sections, so it is not possible by this means alone completely to protect running plant attached to sound sections. At the same time it is clear that the use of busbar reactances operates in a helpful direction.

The figures given apply to the sustained short-circuit values. At the first instant, and before the generator voltage is seriously reduced by armature reaction, the busbar reactances have a much greater effect on the voltage on the sound sections.

VIII. Improvement of Power Factor.

A study of the data now given will bring out the disadvantages associated with the low power factor prevalent in distribution schemes in this country, and it will appear that the requirements for maintaining supply, as well as the conditions for diminishing losses, will be improved if a higher average power factor, such as 90 per cent, is obtained. In these respects present-day American practice has the advantage.

IX. The Interconnection of Stations.

Where relatively small and remote sources of power are coupled to a large system they improve the supply in their immediate neighbourhood. It will generally be found that the inherent reactance in the feeders and transformers is sufficient to prevent excessive increase of short-circuit currents in the neighbourhood.

Where the source is near a large station, it may be treated like a generator tied direct to an extension of the busbars, but will probably have more reactance than a single machine of equal output.

Where large stations are tied together this connection is similar to that between adjacent sections of busbars in an individual station, but differs in that a relatively smaller energy transfer is required, so that higher

* For example, with 10 per cent reactance between sections, the difference will be 1 per cent if the magnetizing current transferred is numerically one-tenth of the rated current capacity of a section. That is to say, to transfer this amount of magnetizing current would require that the busbars should be run respectively $\frac{1}{2}$ per cent above and below normal.

If the load is transferred at 80 per cent power factor the magnetizing component will be 60 per cent of the k.v.a. transferred. If therefore this magnetizing component is limited to one-tenth of the section capacity, the load transferred would be limited to 10/6ths of this figure, i.e. one-sixth of the section capacity, whereas we want to transfer perhaps four times this load.

reactance may be employed. The energy transfer is made only for purposes of economy, and the individual station is already a self-contained economical unit. The short-circuit currents from individual sections in either station will not be materially affected if there are already three or four sections or more.

If the stations are not tied directly but only through the distribution system, intermediate points will be subject to the short-circuit outputs of both stations.

Limitations affecting parallel running.—The question now arises how will the employment of reactances between sections affect parallel running. This becomes particularly important in the case of stations remote from one another tied together for economy. Such ties may not be of large cross-section and may therefore introduce considerable resistance.

The theoretical treatment of this and similar cases has not been entirely satisfactory, but we may recognize that there are lower and upper limits to the reactance between which we can get satisfactory operation. *It has been found that it is not generally practicable to obtain stable running conditions where the ohmic value of the total reactance in circuit between the machines is less than about twice the resistance.* This necessitates the employment of external reactance in series with long underground tie cables of small cross-section. Where, however, there are step-up and step-down transformers in the circuit there will be ample reactance.

There must be an upper limit also, and this also is not easy to determine. It is evident that if two systems are running steadily at about the same frequency and voltage, a very small transfer of energy and magnetizing current passing through a high reactance will bring the two systems into synchronism. If now one system is seriously disturbed it will get out of phase with the other, but the small currents transferred will be insufficient to disturb the sound system and will eventually bring the system into synchronism after conditions have become normal and steady. Here we have parallel running without trouble but without utility.

If now we reduce the reactance in the tie we get heavier synchronizing currents and some disturbance of the sound system, but the two systems take time to settle down after a fault is cleared on one of them, and during this time there is much phase-swinging. This oscillation tends to throw out synchronous machinery and is more serious than mere loss of voltage. The limiting values of reactance are somewhat indefinite, but experience indicates that they are well above the value contemplated in this paper. It is known that with the star design quite satisfactory results can be got with busbar reactances of 40 per cent and more based on the section output, and upwards of 100 per cent has been employed in a tie line between two stations.

X. Influence of Live Load on the Short-circuit Current.

In estimating the effect of reactance on the short-circuit currents no account has been taken hitherto of the influence of running machinery able to feed current back into a fault. This factor is generally a relatively small one. It complicates the issue but must not be lost sight of. In determining the short-circuit current that may flow at any point it is necessary to add the current, due to such machinery, which will flow through the impedance of any feeders, transformers, etc., located between the machines and the point in question.

The short-circuit current, for example, near a large substation with rotary converters may be considerably increased by the current the converters can pump back

XI. Limiting Effect of Fault Resistance.

One must not expect to find any protection from internal resistance of faults, except when the fault is to earth through a poor earth connection or includes a long open arc.

Where porcelain insulators are mounted in brick or stone the supporting wall reinforces the insulation, and, even if a cracked insulator discharges, the current at 6,000 volts will be quickly reduced from perhaps

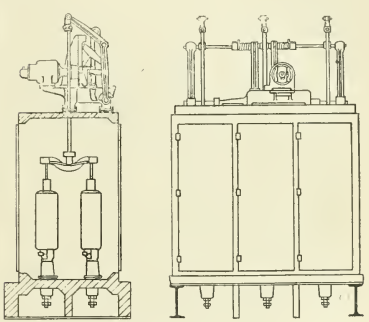


Fig. 7.—Oil switch showing good insulation to earth and between phases.

5 amperes to a negligible figure as the wall dries by the heat generated.

In the case of carbonizable material, however, as in cables and machine windings, the energy liberated at the fault will cause the conductivity to develop in a small fraction of a second to a figure offering no further limiting effect.*

The development of a fault is sometimes stopped at

* On a system working at, say, 6,000 volts to earth, a fault to earth of only 1 ampere releases 6 kilowatts to heat up the insulating material locally, and when the resistance has fallen to 5 ohms there will be a local application of more than 7,000 kw., so it is clear that the development must be extremely rapid in the later stages. On insulated systems operating at 6,000 to 10,000 volts, and even where the current to earth is limited to a capacity current of, say, 10 to 20 amperes, the first indication of a fault to earth is always the occurrence of a dead short-circuit to earth.

What happens is that the insulating material is carbonized locally so completely that the fault resistance is reduced to a point such that the energy liberated almost ceases to cause further destructive heating.

an intermediate stage by quick-acting switchgear set to operate at a few amperes, but this is not a means which can be relied on for effectively limiting the stresses at a given point in the system.

Limiting stresses by preventing faults between phases.—As faults to earth can be positively limited by the employment of resistance in the earth connection, it is only faults between phases that present a serious problem. The likelihood of such faults occuring can be greatly minimized by appropriate design.

When conductors are air-insulated they may be separated by substantial insulating barriers and kept clear of earthed metalwork. The barriers should be sufficiently large and substantial to confine the disturbance arising on failure of the apparatus they separate.

A good example is to be found in a large oil switch constructed as in Fig. 7 with insulated tanks, those on each pole being enclosed in a stone or brick cell.

Conductors surrounded with insulating material may be further separated by earthed metal barriers so arranged that a fault to earth is confined to the phase on which it occurs.

A good example is found in a machine in which the conductors throughout their length, including the end turns, are covered with insulating material and separated by earthed metal parts with which they are in intimate contact. A breakdown on such a machine must arise as a fault to earth, and is localized by the formation of a good enclosed conducting path to earth. The risk of open arcing is minimized, and consequently the risk of the fault spreading to other phases and consuming the whole machine.

XII. Limiting Disturbances by the Use of Protective Relays and the Like.

The advantages obtained by the use of selective protective apparatus on large distributing systems are now generally recognized. They play an important part in economical distribution and an essential part not only in localizing disturbances but in limiting their duration. This latter function is useful in preventing the development of disturbance due to unstable conditions, as for example in parallel running, but is especially important on large plants where the factor of safety against overheating on short-circuits is likely to be small.

The use of such apparatus throws a severe duty on the switchgear, as switches have to clear faults whilst the currents are in the neighbourhood of maximum value (see Fig. 1), and the onus of clearing each particular fault is thrown on the individual switch or switches nearest to it.

For these reasons it is necessary to employ with the selective protective apparatus a system of stand-by protective apparatus which comes into use in case of failure of switchgear or selective apparatus. This takes the form of a system of fixed time-limit relays with graded settings which will come into operation only after failure in the first line of defence. A plant so protected will be as well off even on failure of the selective apparatus or distribution switchgear as plants have been in the past which were protected solely by the apparatus now used as a stand-by.

It is clear, therefore, that the provision of an adequate stand-by system justifies working with a lower factor of safety on the smaller circuits, especially if the conditions are favourable and the plant well designed in the first place to minimize the occurrence of severe faults. Existing switchgear may be retained on extension of plant, by relying on the stand-by protection to save the plant, if the margin is not too small.

For example, switchgear rated at 20,000 k.v.a. might be employed to clear faults of 30,000 to 40,000 k.v.a. with stand-by protection, as, if the conditions are favourable to the switch, even the larger faults may be cleared satisfactorily and the severest disturbances should be few and far between.

In concluding, I desire to acknowledge my indebtedness to Messrs. The British Thomson-Houston Co., Ltd., for facilitating the preparation of this paper, and to Mr. A. R. Everest and other of my colleagues for valuable assistance.

APPENDIX I.

Rupturing Capacity of Oil Switches.

Switches for any particular system must be rated to give satisfactory operation (1) under the severest emergency conditions, and (2) under normal service conditions. This requires the following:—

(*a*) They must break with certainty the maximum possible short-circuit they may be subjected to.

(*b*) The damage to the switch should be such as not to interfere with the commercial operation of the plant.

The second condition is the one which requires watching. For the usual conditions of electrical distribution it is quite sufficient if the switch will break the maximum short-circuit current twice and after this be capable of carrying normal current.

For railway service and other heavy power service, where heavy short-circuits may be frequently met with, the switch will require to withstand the corresponding frequently-repeated shocks and destructive arcing and must be rated accordingly.

Switches are obtainable able to cope with the severest conditions likely to be met with in this country for some time to come, and with a long record of good service behind them, giving the only possible non-speculative guarantee of their reliability under all manner of working conditions.

Switches have been employed in this country for many years past having great mechanical strength, chambers able to resist high explosive forces, high speed of break, and suitable contact design. These and other features all serve to give high rupturing capacity.

The designer's data is still largely empirical, and, as always happens in such cases, there are many ideas in circulation in the nature of half-truths, such, for example, as that switches should be compared by comparing the length of break.

The above features in design are being incorporated in an increasing degree in switches of small size, with the intention of increasing the rupturing capacity without increase of dimensions and without much increase of cost. This is all to the good, especially in the reduction of the cost of main switchgear for small plants, but some warning is required against carrying this principle too far in designing switchgear for use on small circuits subject relatively frequently to severe short-circuits. Increasing the strength, while it increases the power of the switch to withstand heavy stresses, contributes nothing towards reducing burning. Now, on switches of the design at present in general use (of which Fig. 30 is typical) we get very little burning and consequent gas production so long as we keep well within the rupturing limit proper to the dimensions of the switch, and after this is exceeded gas production and burning rapidly increase. The present demand for switches of great mechanical strength is not justified in so far as it arises from unfortunate experiences with over-rated switches. On the other hand, the increase of mechanical strength is valuable where the normal service is easy but where one has to provide against an unlikely contingency.

There has been no radical departure in the design of oil switches in recent years, and, until we have some important discovery to help us, switches will remain pretty much as they are now. Cost figures are of little value in the present state of the market, but it may be said that rupturing capacity and cost of switchgear equipments vary roughly in simple proportion.

In interpreting the maker's rating of oil switches it is very necessary to take account of the class of service for which the switch has been designed. A switch may be suitably rated for 1,000 amperes and 6,000 volts, and yet may be quite unsuitable for use on a 500-volt circuit where it is called upon to make circuit on several hundred amperes several times a day. It may have been designed with the large rupturing capacity required for emergency service on the busbars of a large 6,000-volt station, yet may have quite insufficient provision for withstanding the wear and tear on a circuit of the kind described. It may open with certainty 40,000 k.v.a. on a short-circuit without damage to the main contacts, and yet fail to destruction on what might appear to be the easy condition of controlling a 500-volt motor.

Switches for industrial use in factories and the like, if well designed, have a rupturing capacity of 5,000 to 15,000 k.v.a. Switches for consumers' premises and substations will rupture about 10,000 to 35,000 k.v.a. according to size. Next there are lines of switches rated in the neighbourhood of 100,000 to 200,000 k.v.a., suitable for stations up to 30,000 k.v.a. and for large substations on much larger plants, and finally a few switches rated to deal with any conditions likely to arise under conditions now anticipated.

Switches of such ratings can be purchased at figures suitable for their position in the system, and it will be found that these same limits correspond to what is required in the different parts of the system to obtain good running conditions from every standpoint.

APPENDIX II.

Rating of Reactances.

In discussing the use and characteristics of reactances it is most convenient to rate them in terms of the percentage reactive voltage drop they will give on the full-load rating of the part of the plant with which they are associated. Thus we speak of a transformer with 1 per cent reactance. In the same sense a reactance for a generator and rated at 10 per cent is understood to absorb 10 per cent of the normal voltage when carrying the rated current of the machine.

In the case of busbar reactances each reactance is associated with a section of the busbar and should be rated on the total generator capacity attached to the section, as its current-limiting effect is independent of how that capacity may be subdivided.

For example, in Fig. 5 the generator and transformer reactances are rated 10 per cent and 4 per cent respectively on their individual outputs, and the busbar reactance is rated 14 per cent on a busbar section rating of 40,000 k.v.a. It will be seen that the reactance drop is the same for a fault on either busbar section although the generator capacity on one side is made up of two machines.

A feeder reactance may be rated at 3 per cent when associated with the feeder, but if its effect on short-circuit is considered in connection with a generating plant of 10 times the feeder rating, it at once becomes 30 per cent. When rated in this way it may be added to the reactance of the generators expressed in the same terms. If, for example, the generator reactance is 10 per cent, the total is 40 per cent based on the generator rating, and limits the maximum short-circuit current to $2\frac{1}{2}$ times the rated output of the generators.

Thus this method of rating enables the employment of reactances to be discussed in general terms and without reference to the size and voltage of the plant.

The current-carrying capacity which may be given to a reactance has no effect on its current-limiting action, and is determined by consideration of the amount of power to be transferred through it.

The actual dimensions of a reactance will of course depend both on its ohmic value and on its current capacity, and the individual reactance is best rated in amperes, carrying capacity, and ohms reactance at a given frequency, with the addition of working voltage, the working voltage determining the insulation required.

APPENDIX III.

Arrangement of Busbars.

In the provision of busbars and switches, something more is required than a simple straight busbar, or even a single ring busbar with one switch per circuit. Additions are made both to give duplication for safety and to provide flexibility. An extreme is reached by a design like an arc plug-board with provision for coupling any circuit or group of circuits independently to

any machine. Such a design has been provided for (*Proceedings of the American Institute of Electrical Engineers*, 1916, vol. 35, p. 886) and gives maximum

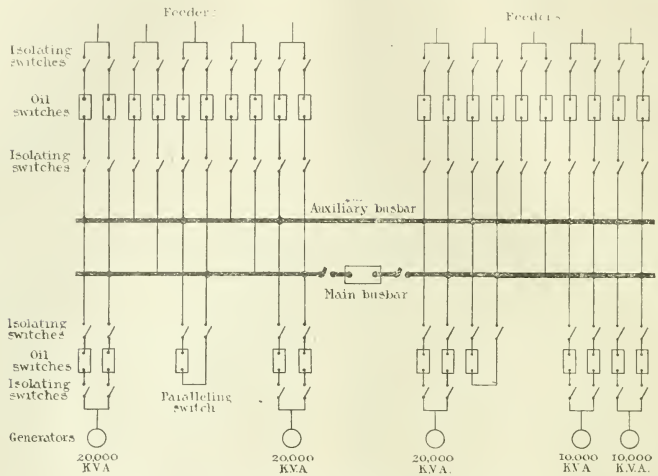


FIG. 8.—Arrangement of switchgear showing duplicate busbars.

flexibility with something more than duplication. In a station with 5 machines and 10 feeders, 15 busbars

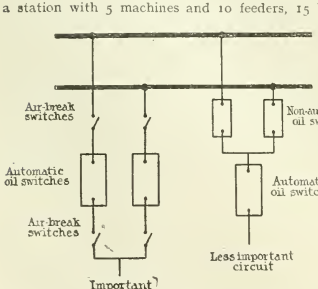


FIG. 9.—Duplication of oil switches.

would be required, and 50 oil switches, as against one busbar with 15 oil switches.

The first essential is a spare busbar arranged so that any section can be shut down without interfering with supply. In the matter of switches it is recommended that all normal switching operations should be done by means of oil switches, and that air-break switches should be used only for isolating parts already made dead by oil switches. By this course adequate duplication is provided and the risk of serious trouble due to operator's mistakes in routine work is reduced to a minimum.

Thus with provision for busbar paralleling and sectionalizing, a station such as described may usefully employ, say, 33 oil switches without reactances (see Fig. 8).

Each addition to the primitive arrangement should be made to give a definite contribution to the results obtainable, and it is a general law of design that there will be increased economy if there is differentiation of function as well. For example, in the illustration given, one of the busbars is regarded as the main busbar and given a section switch. The other is regarded as the stand-by and would be used as a hospital busbar and for testing. The arrangement has all the advantages of a single ring busbar and at the same time provides a stand-by. It does not look like a ring because coupling switches are not shown at the ends, but each section is in fact coupled to both its neighbours, and the paralleling switches are located midway in the length to keep down the cross-section of copper. For the same reason the machine and feeder switches are alternated.

If oil switches are not duplicated, the fact of an oil

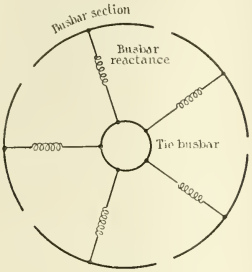


FIG. 10.—Star design of busbars and reactances.

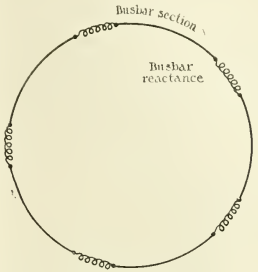


FIG. 11.—Ring design of busbars and reactances.

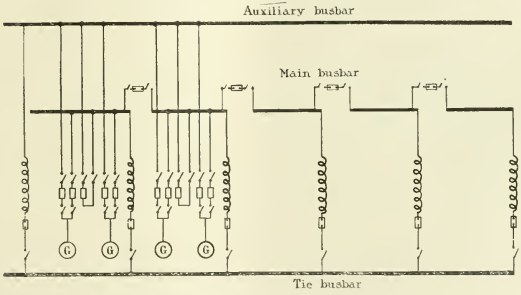


FIG. 12.—Arrangement of switchgear for star design.

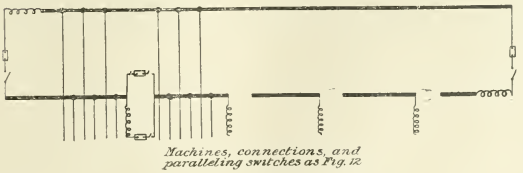


FIG. 13.—Arrangement of switchgear for ring design.

switch being put out of commission for any reason prevents the corresponding machine or feeder being employed, and thus must lead in the long run to greater expenditure on spare plant or a greater risk of serious lack of spares on emergency.

For this reason large machines should have at least two switches, but on less important circuits a compromise can be effected by employing one automatic oil switch and two inexpensive non-automatic oil-break selector and isolator switches as in Fig. 9, but economy is effected in first cost thereby only where the main oil switches are required to be of large rupturing capacity. It will be understood that the oil-break selector switches will break load current without danger, which an air-break switch would not do.

Arrangement of busbars with reactances.—Busbar reactances may be employed in either of two ways, conveniently described as the star and the ring designs.

In the star design the busbar reactances are paralleled by tying them to a common point or tie busbar as in Fig 10, whilst in the ring design each busbar section is tied to the next through a reactance, as in Fig. 11.

In introducing reactances, two oil switches will be required with each. One is for paralleling through the reactance and the other for paralleling without the reactance. These switches are so employed that the number of machines tied direct to any group of solidly paralleled sections does not exceed the number proper to one section, and is not appreciably less. For example, with two machines per section, two sections should not be solidly paralleled unless at the time they have only one machine running on each. They will be separated by reactance immediately a third machine has been coupled to them. At times of heavy load all the reactances will be in use. At times of light load they will all be short-circuited. This is necessary, for it will be found that with reactances of the ohmic value required it is not always practicable to transfer light load through them without excessive drop of potential.

The complete switchgear in accordance with these recommendations is shown in Figs. 12 and 13, in which the feeders are omitted for simplicity.

It will be seen that, with the five sections shown, six reactances are required in each case. With the star arrangement the sixth is used to tie in the auxiliary busbar. With the ring arrangement a tie is required at both ends so as to ensure a reactance between this busbar and each adjacent busbar. Each arrangement is in effect a six-section busbar.

Each reactance as here shown is associated with a particular busbar to which it is solidly tied, but an isolating switch can be introduced at this point at small cost, giving greater flexibility.

The paralleling switches shown are all essential if duplicate main oil switches are not employed, but where the busbars can be paralleled through one or more pairs of these duplicate switches, the paralleling switches are not essential. The two end ones should be retained for uniformity in the equipment for completing the ring main. Their use throughout as shown is recommended, however, as it simplifies and unifies the operations and the amount of thought required.

Advantages of the star arrangement with its extra busbar will be brought out by a study of these diagrams. Whatever sections are employed are paralleled by the simple operation of coupling them to the tie busbar, whereas in the ring arrangement it is not possible to maintain the ring formation when one section is shut down, or easy to follow the load-transfer conditions. Mistakes are more easily made which will leave the reactances cut out and too many machines operating in parallel on a section.

The third or tie busbar needs to be at least as well made as the other two, as a fault on that busbar involves all the sections and is fed through all the reactances in parallel.

This busbar may be conveniently mounted close to the reactances. It is not duplicated, but may be ringed and broken up with air-break switches. It can be made dead at any time by a temporary sacrifice of economy in running.

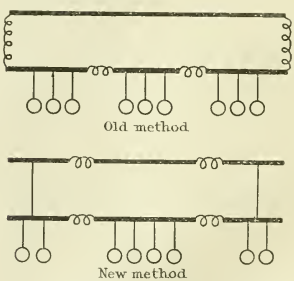


FIG. 14.—Distribution of machines in ring design.

There is no doubt, however, on the other hand, that in many situations it is easier to make a good design with two busbars than with three, so that there is a use for the ring arrangement. It will be shown that the load-transfer capacity of the reactances required in the ring arrangement may be as much as that required in the star arrangement, and the ohmic value is doubled for the same protective value, so the k.v.a. rating of reactances for the ring design may be twice that required for the star design and the cost consequently about 50 per cent higher. This is partly or wholly offset by the omission of the third busbar. The ring arrangement, however, has the defect that under working conditions the ring cannot always be maintained closed. On shutting down any section of the busbar the ring is broken. If the design gives the correct limits with a closed ring it will now be found that there is too much reactance isolating the end sections of the open ring and consequent excessive pressure drop, whilst if the reactances are selected to compromise for this, clearly this can be done only at the expense of the protection afforded. The balance of advantage lies with the star design.

The defect in the ring system can be partly offset by making the end sections 30 to 50 per cent smaller than the middle section and arranging them as shown in Fig. 14.

APPENDIX IV.

Current-limiting by the Use of Busbar Reactance.

The question is how far in the system generally can the short-circuit current be controlled by the use of busbar reactance in the generating station.

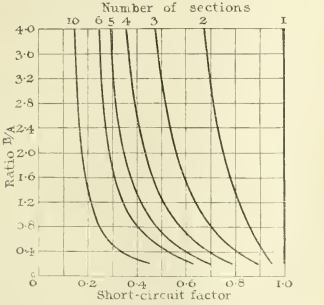


Fig. 13.—Reduction of short-circuit by the employment of reactances in closed ring.

The value of the short circuit current depends upon five variables: —

(*a*) The working voltage.
(*b*) The total generator capacity.
(*c*) The generator reactance whether internal or external.
(*d*) The busbar reactance.
(*e*) The number of busbar sections.

The results obtainable may be reduced to a single diagram, using the short-circuit current obtainable without busbar reactance as a unit. This is readily ascertainable as follows:—

$$\text{Short-circuit k.v.a.} = \frac{\text{Total generator k.v.a.} \times 100}{\text{Percentage generator reactance}}$$

Taking this as the unit, Figs. 6 and 15 show the reduction obtained with different values of busbar reactance "B" expressed in terms of the generator reactance "A" and for different numbers of busbar sections.

Fig. 6 represents the star design and Fig. 15 the closed ring design. In the latter, current is fed from both sides so that reactances are required of about twice the ohmic value for the same degree of protection. In Fig. 15, therefore, the vertical scale has been doubled, and with this alteration it will be seen that the two sets of curves are very similar.

In Fig. 6 from the bottom of the diagram it is evident that the introduction of a small amount of busbar reactance has a big effect in reducing the short-circuit values. As the reactance value is increased its effectiveness by no means increases proportionally. The same is true of increasing the number of sections. The curves are figured from the following formula, giving the factor *f*, that is, the ratio between maximum short-circuit currents with and without reactance:—

$$f = \frac{(N-1)+\left(\frac{B}{A}N+1\right)}{N\left(\frac{B}{A}N+1\right)}$$

where A = generator reactance,
B = busbar reactance,
N = number of sections.

The results are shown in a different form in Fig. 16, the horizontal ordinates in which are the inverse of

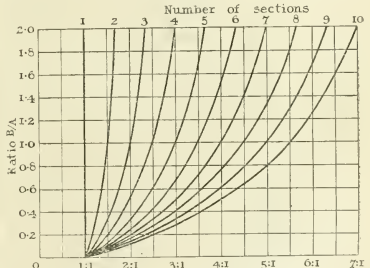


Fig. 16.—Reduction of short-circuit with star design.

those in Fig. 6. It will be noticed that the factor *f* has equal increments for each additional busbar section.

These curves are based on the assumption that the full complement of generators is connected to each busbar section, whereas the worst case in practice is shown in Fig. 17. Separate curves would be required for each case there shown. The above curves give results a little on the high side if the total generator capacity is taken as a basis, and on the low side if the maximum of machines running on maximum output is taken as a basis.

These curves cover the ground of what is practicable, as it will be shown later that the amount of busbar reactance permissible is limited by the permissible voltage difference between busbar sections, and that in the endeavour to keep down short-circuit stresses the

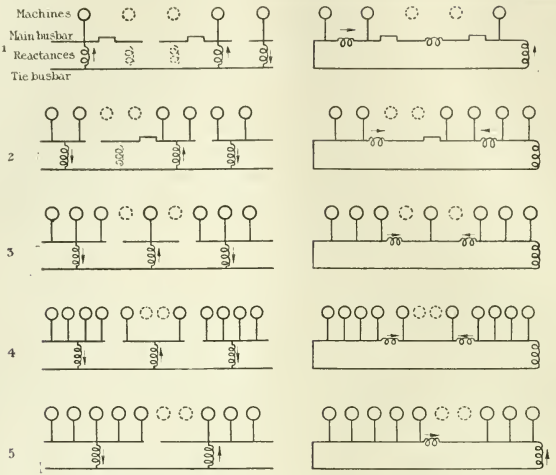


FIG. 17.—Combinations of machines requiring maximum transfer capacity.

increase of generator reactance will keep down the ratio well within the range of the above curves and within

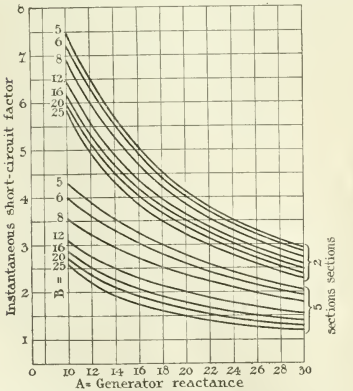


FIG. 18.—Combined effect of generator and busbar reactances, star design, with two and five sections.

economical limits. These are the factors which will be found to determine the cost, but a few words may be said here on the question of the best value of the ratio B/A from the cost aspect.

We have to consider the total protective value obtained

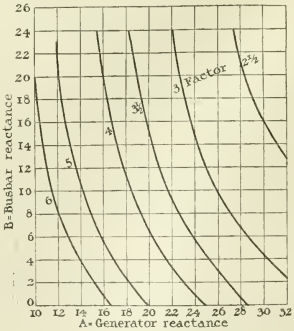


FIG. 19.—Combinations of B and A giving equal protection, star design, with two sections.

with generator plus busbar reactance, and this is indicated in Fig. 18, in which the vertical scale gives the number of times the short-circuit current exceeds the

normal output of the machines. It should be noted that these curves are figured on the total plant capacity and not on the maximum output of the plant. They show the ratio for two and for five sections and with different values of busbar reactance.

Based on these, Figs. 19 and 20 have been prepared showing different combinations of generator and busbar reactance giving equal protection.

So long as the generator reactance can be provided internally the cheapest combination will be that with minimum busbar reactance, but even if all necessary protection of plant could be obtained with generator reactance alone it would still pay to employ busbar reactance owing to the protection afforded to continuity of supply.

In case some of the reactance is put external to the generators there will be a value of B/A giving minimum

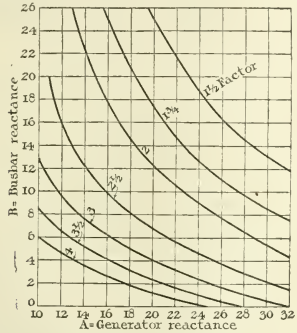


FIG. 20.—Combinations of B and A giving equal protection, star design, with five sections.

cost. This ratio can be varied over wide limits without materially affecting the cost, and the best figure depends upon how much reactance is external and upon the number of busbar sections and transfer capacity required. As a rough guide it may be said that for five busbar sections the minimum is reached when B/A is in the neighbourhood of unity, and with two sections when B is 1/3 A, but either ratio may be varied by 2 or even 3 to 1 without seriously affecting costs, so here again we have to look to technical grounds for our limiting features.

APPENDIX V.

TRANSFER OF LOAD THROUGH REACTANCES.

The conditions requiring the largest load transfer with different numbers of machines per section are illustrated by Fig. 17. The relation between the generator capacity tied to a section and the maximum load on that section is scheduled below on the basis of machines of uniform size and of two spares. In practice one has to deal with unequal sections and machine capacities, but one aims at equal sections and generator capacity per section, two small machines counting as one large one. The spares of largest size are the principal determining factor, so that the conclusions drawn give a good idea of what is required and indicate the basis on which individual cases should be worked out.

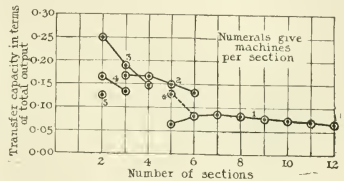


FIG. 21.—Transfer capacity of reactances (star design).

Referring to Fig. 17, the diagram for two machines per section is typical. In this, the worst case occurs when the station is fully loaded, i.e. all but the two spares machines are running, and the two machines shut down are on the same section. The section is tied solidly to the adjacent section, forming one section with two machines directly connected, this being the permissible maximum. One reactance is also cut out, so that the doubled section is properly protected by a single reactance.

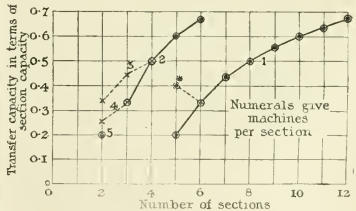


FIG. 22.—Transfer capacity of reactances (star design).

The conditions shown in the figure will arise not only out of necessity but also out of convenience in the normal operation of the plant, and should be met by the provision of ample carrying capacity in the reactance, rather than by special switching operations involving the use of the auxiliary busbar.

Schedule A gives the transfer capacity for the star design for each of the cases illustrated. On referring to Fig. 17, and to the diagram for the ring design, it will be seen that the transfer capacity in the first figure must be the same for both ring and star design. In the remaining cases in the ring design the

transferred load is divided between two reactances which so long as the ring is closed could therefore have half the current capacity. On the other hand if the ring is broken, as it is bound to be from time to time, then in the worst case one reactance must carry the total transfer as in the star design. This worst case is most likely to happen if there are only two busbar sections, and will happen in the other cases if we have two machines on one section down and need to shut down an adjacent busbar at full load, a rather unlikely contingency. If this case arises and is not provided for, then we shall be compelled temporarily to cut out reactance or operate with excessive potential difference.

With the ring design a compromise can be effected by allowing, say, three-quarters of the capacity shown for the star design.

A study of Fig. 21 will bring out the meaning of the data scheduled.

It will be noted that for a given total output and number of machines per section, the transfer capacity required does not vary much with the number of sections. The falling-off would be compensated if with the larger number of machines more than two spares were provided. It should also be borne in mind that the figures are based on one size of machine throughout, whereas on some sections, and especially the first installed, there will be an equivalent capacity made up of smaller machines. These require less transfer, so that in actual conditions the capacity required is practically determined by the final total output aimed at, and must be made sufficient for this.

SCHEDULE A.

Transfer Current Capacity of Reactances: Star Design.

Number of Sections	Total Generator Capacity one Machine as Unit	Maximum Total Output, two Spares	Output per Section, one Machine as Unit	Sections Coupled in Worst Case	Output of Coupled Sections, one Machine as Unit	Load transferred to Coupled Sections, one Machine as Unit	Load transferred to Coupled Sections, Generator Capacity of one Section as Unit	Load transferred to Coupled Sections, Total Generator Capacity as Unit	Load transferred to Coupled Sections, Total Output as Unit
One Machine per Section.									
5	5	3	0·60	2	1·20	0·40*	0·4*	0·08*	0·133*
6	6	4	0·67	2	1·33	0·33	0·33	0·055	0·083
7	7	5	0·71	2	1·43	0·43	0·43	0·061	0·086
8	8	6	0·75	2	1·50	0·50	0·50	0·062	0·083
9	9	7	0·78	2	1·56	0·56	0·56	0·062	0·080
10	10	8	0·80	2	1·60	0·60	0·60	0·060	0·075
11	11	9	0·82	2	1·64	0·64	0·64	0·058	0·071
12	12	10	0·83	2	1·67	0·67	0·67	0·056	0·067
Two Machines per Section.									
3	6	4	1·33	2	2·67	0·67	0·33	0·111	0·168
4	8	6	1·50	2	3·00	1·00	0·50	0·125	0·167
5	10	8	1·60	2	3·20	1·20	0·60	0·120	0·150
6	12	10	1·67	2	3·33	1·33	0·67	0·111	0·133
Three Machines per Section.									
2	6	4	2·00	1	2·00	1·00	0·33	0·167	0·250
3	9	7	2·33	1	2·33	1·33	0·44	0·148	0·190
4	12	10	2·50	1	2·50	1·50	0·50	0·125	0·150
Four Machines per Section.									
2	8	6	3·00	1	3·00	1·00	0·25	0·125	0·167
3	12	10	3·33	1	3·33	1·33	0·33	0·111	0·133
Five Machines per Section.									
2	10	8	4	1	4·0	1·00	0·20	0·10	0·125

* In this case one reactance carries load transferred to two coupled sections. In all other cases two or more share it.

For a given amount of protection and number of sections, the number and ohmic value of the reactances are fixed, so the cost varies only with the transfer capacity. These curves therefore give a good idea of the relative cost for different numbers of machines per section. It will be seen that one machine per section gives the lowest cost, but in some cases with an impracticable number of sections.

Further calculation shows that the cost of the reactances for a given measure of protection decreases with an increase in the number of sections, but on the

other hand the cost of the necessary switchgear for the larger number of reactances is increased, and investigation of two typical cases indicates that the balance is negligible.

It is clear, therefore, that in considering the best number of sections to employ, the question of cost of the reactance equipment is not a guiding feature.

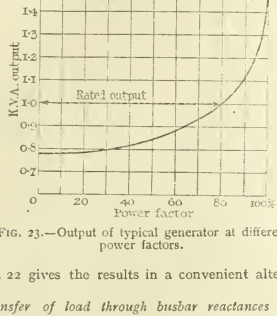


FIG. 23.—Output of typical generator at different power factors.

Fig. 22 gives the results in a convenient alternative form.

Transfer of load through busbar reactances at high power factor.—When energy is transferred from one busbar section to another at a power factor higher than that of the load, the shortage of magnetizing current has to be made good by the machines connected to the

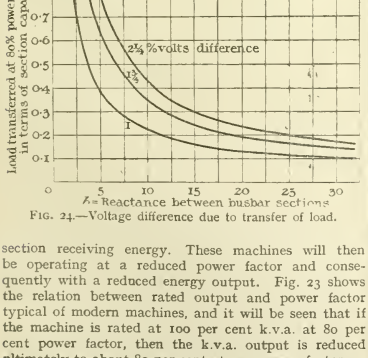


FIG. 24.—Voltage difference due to transfer of load.

section receiving energy. These machines will then be operating at a reduced power factor and consequently with a reduced energy output. Fig. 23 shows the relation between rated output and power factor typical of modern machines, and it will be seen that if the machine is rated at 100 per cent k.v.a. at 80 per cent power factor, then the k.v.a. output is reduced ultimately to about 80 per cent at zero power factor.

Fig 24 shows the voltage difference required for the transfer of load at 80 per cent power factor through reactance between busbars, the reactance in this case being the effective reactance of any combination of units there may be in series and parallel between the sections in question.

Fig. 25 shows the advantage of furnishing magnetizing current from the machines running in the section to which energy is being transferred. The load is again taken at 80 per cent power factor. The lower curve requires transfer of load at 80 per cent power factor. With the top curve the whole current output of the machines running on the section is taken as magnetizing current. It will be seen in this case that with half the machines running, if the section output is to be three-quarters of the section capacity (i.e. allowing 25 per cent spare plant), one is limited to 11 per cent equivalent reactance between machines, but this rapidly increases up to a theoretical limiting figure of 30 per cent as the power factor of the running machines is decreased.

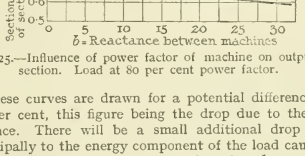


FIG. 25.—Influence of power factor of machine on output of section. Load at 80 per cent power factor.

These curves are drawn for a potential difference of $1\frac{3}{4}$ per cent, this figure being the drop due to the reactance. There will be a small additional drop due principally to the energy component of the load causing I R drop. This will be in general less than $\frac{1}{4}$ per cent, so that the figures of $1\frac{3}{4}$ and $2\frac{1}{2}$ per cent chosen correspond to a maximum difference of about 2 and $2\frac{1}{2}$ volts, or a variation from normal of 1 and $1\frac{1}{4}$ per cent in volts.

We can now determine the maximum value of busbar reactances for different conditions of running. These are set forth in Schedule B. This Schedule is prepared to cover different numbers of machines per section and of sections, and covers a very wide range, because it will be found that with a given number of machines per section, the number of sections does not exercise much effect; for in the first place one has to allow from the commencement the transfer capacity that will be necessary in the complete installation, and in the second place it will be found that if each likely combination of machines and sections is worked out in detail the maximum values of B do not vary much with the number of sections.

The third line shows the maximum load transfer required at full load in the most unfavourable case as shown in Fig. 17, and the next line shows the maximum value of B for $2\frac{1}{2}$ per cent voltage difference, the load being transferred at 80 per cent power factor.

If we meet this extreme case by adjustment of the machine power factor we get at once a big increase in the possible amount of reactance, and with a voltage variation of 1 per cent from normal we can get the results shown in line 5.

Generally at full load on any one section we can arrange to have not more than one machine shut down on that section, and can thus transfer at 80 per cent power factor through much larger reactances. The figures are given in line 7.

For investigation of the limiting effect on short-circuits the author has assumed this to be the normal condition of operation, and that adjustment of power factor will be resorted to only in the extreme case and then will be limited to 50 per cent power factor. We then get the permissible maximum B by combining lines 5 and 7. The result is shown in line 8 and does not necessitate approaching the 50 per cent power factor limit except where there are 3 or 4 unit machines per section.

Based on these figures for B, the short-circuit factors are figured and shown in Schedule C. This factor is the figure by which the rated capacity or output, as the case may be, must be multiplied to get the maximum instantaneous output on short-circuit.

APPENDIX VI.

Design of Current-limiting Reactances.

The special feature of reactances employed for current-limiting is that the current they have to limit on emergency is many times the maximum current they may have to carry continuously. This feature puts these reactances in a class by themselves, and must be kept in mind in comparing different designs.

There is no gain in the use of iron in the design, as in order to ensure the correct reactance under heavy currents the iron has to be worked at very low densities under normal running. In most cases the employment of iron will not give a cheaper design, but there are also other good reasons for avoiding its use.

These reactances are required generally for important circuits, and principally for use in busbars, and it is important that their use should not lower the factor of safety on the system. There are great and obvious

Schedule B.—Star Design.

Maximum Value of B for Different Conditions.

(1) Machines per section	1	2	3	4	5
(2) Number of sections	7	5	4	3	2
(3) Transfer capacity, worst case	0·43	0·60	0·50	0·33	0·20
(4) Maximum B for 2½ per cent difference	5	4·6	5·7	7·6	9·2
(5) Maximum B for 1¾ per cent difference in volts with machines at 50 per cent power factor	Above 25	Above 25	9	16·5	Above 25
(6) Transfer capacity, one machine off	0·43	0·30	0·17	0·08	0·00
(7) Maximum B for 1¾ per cent difference in volts with machines at 80 per cent power factor	4	7·2	11·5	Over 25	Over 25
(8) Maximum B for conditions (5) and (7)	4	7·2	9	16·5	Very large

Schedule C.—Star Design.

Short-circuit Factor.

Machines per section	One		Two			Three			Four	
Number of sections	5	6	4	5	6	2	3	4	2	3
Number of machines	5	6	8	10	12	6	9	12	8	12
Bus reactance B	4	4	7½	7½	7½	9	9	9	16	16
Generator reactance A	*Factor in Terms of Total Capacity.*									
10 per cent	3·8	3·6	4·1	3·5	3·1	5·6	4·5	3·4	5·6	4·2
15 ,,	2·8	2·7	3·0	2·7	2·4	3·8	3·3	2·7	5·1	3·0
20 ,,	2·2	2·2	2·4	2·2	2·0	2·6	2·6	2·1	3·0	2·4
30 ,,	1·6	1·6	1·8	1·7	1·5	2·1	2·0	1·6	2·1	1·8
	Factor in Terms of Maximum Output.									
10 per cent	6·3	5·4	5·4	4·4	3·7	8·4	5·8	4·3	7·5	5·0
15 ,,	4·7	4·1	4·0	3·3	2·9	5·8	4·2	3·2	6·8	3·6
20 ,,	3·7	3·3	3·2	2·8	2·4	4·4	3·4	2·6	4·0	2·9
30 ,,	2·7	2·5	2·4	2·1	1·9	3·0	2·4	1·9	2·8	2·1
	Factor in Terms of Section Capacity.									
10 per cent	19	22	16	18	19	11	14	14	11	13
15 ,,	14	16	12	14	14	8	10	11	10	9
20 ,,	11	13	10	11	12	5	8	8	6	7
30 ,,	8	10	7	9	9	4	6	6	4	5

advantages in employing a design in which all parts are fully open to inspection, and this is impossible where iron is employed.

It is essential that the device shall perform its function when an emergency arises. With a closed design with iron core some defect may develop and be overlooked until failure occurs, owing to the impossibility of examining individual windings without taking the whole thing to pieces and re-building it.

Figs. 26 and 27 illustrate a reactance designed for this class of service and showing how readily all parts can be inspected. The coils are of bare copper, so there is no insulating material to give trouble. The only

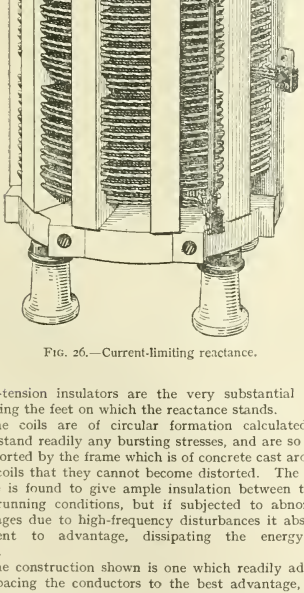


FIG. 26.—Current-limiting reactance.

high-tension insulators are the very substantial ones forming the feet on which the reactance stands.

The coils are of circular formation calculated to withstand readily any bursting stresses, and are so well supported by the frame which is of concrete cast around the coils that they cannot become distorted. The concrete is found to give ample insulation between turns for running conditions, but if subjected to abnormal voltages due to high-frequency disturbances it absorbs current to advantage, dissipating the energy as heat.

The construction shown is one which readily admits of spacing the conductors to the best advantage, and ample ventilation, and the materials employed are non-inflammable.

A reactance of this kind installed in a brick chamber cannot break down to earth, as there is no good earth in the neighbourhood.

APPENDIX VII.

HEATING AND STRESSES DUE TO HEAVY CURRENTS.

We have now considered how the concentration of power on a fault occurring can be limited. We have yet to consider the heating and stresses due to the large currents still to be dealt with, both under normal and under faulty conditions.

Electromagnetic stresses on conductors.—In modern practice conductors in different phases may be spaced at 1-in. centres or less as in cables, or at 2-ft. centres or more as in large switchboards.

With adjacent conductors at 12-in. centres carrying current in opposite directions, the maximum repulsive force between them will be 9 lb. per foot run for 10,000 amperes, R.M.S. value. The force varies inversely as the distance and proportionally to the square of the current, and often attains serious proportions in modern practice.

In a three-phase cable carrying 100,000 amperes on a fault the force may reach a maximum of 12,000 lb. per foot run, and would approach this in the joint boxes.

Conductors spaced 1 foot apart will be subjected to 900 lb. per foot run on the same current. If the conductors are securely fixed at the ends, the stress on the end supports may be many times this. It becomes essential to support the bars in such a way as to prevent these forces from causing destruction.

A current of 100,000 amperes may be met with on the direct-current side of large rotary converters and on the low-tension side of large power transformers, as well as on the high-tension circuits in very large power stations.

In current transformers designed with multiple-turn primary windings and with coils lying side by side, large forces are produced on short-circuit, tending to drive the coils apart and distort the ends if unsupported.

With typical modern designs the safe limit is reached when the currents are of the same order of magnitude as indicated below also for heating limits. The transformer should not be subjected to more than 200 times normal load current.

Where a conductor forms a loop there is a force tending to expand the loop, the magnitude of which is given by the following formulæ :—

$$\text{In Fig. 28 (A)},\ F = \frac{9\,C^2}{D}\left(\log_e \frac{4\,D}{d} + 0{\cdot}1\right) \times 10^{-8}$$

$$\text{In Fig. 28 (B)},\ F = \frac{9\,C^2}{D}\left(\log_e \frac{2\,D}{d}\right) 10^{-8}$$

where F=lb. per inch,
D=inches,
C=amperes.

These cases are illustrated by Fig. 28, and, based on the figures they give, a fair estimate may be made of most cases which arise in practice.

A 300-ampere isolating switch of the type shown in Fig. 29, or an oil switch of the type shown in Fig. 30 with insulators at 10-in. centres, may have a force of 100 lb. distributed over the blade on a current of 20,000

amperes, or 600 lb. for 50,000 amperes. If the switch be designed as in Fig. 31, the conductors will be almost in line with the blade, and the force due to the loop formation will be relatively negligible.

is reached the force will be again something like 3 lb. per inch run.

Design of large conductors.—Up to about 2,000 amperes' capacity the design of conductors for alternat-

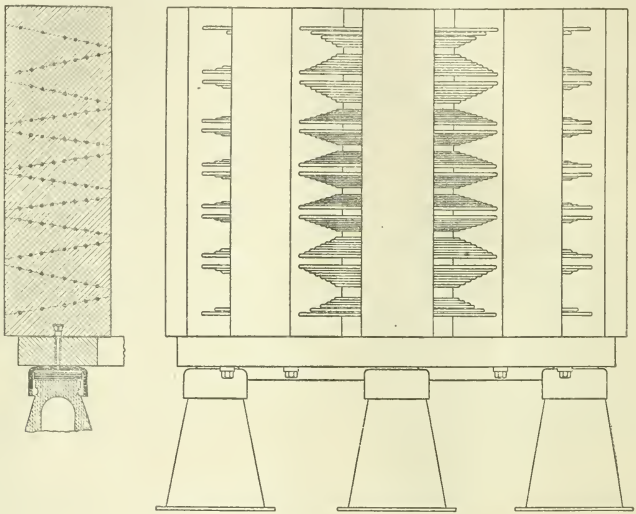


FIG. 27.—Section of current-limiting reactance.

It is good practice to lock or latch the blades of all back-connected isolating switches on 6,000-volt plants where the output may reach 10,000 k.v.a. or upwards, and to latch all switches where the output may exceed

A B

FIG. 28.—Diagrams showing force in conductors carrying current.

20,000 k.v.a. These figures are typical of what is required.

The forces acting on the conductor carrying current in the arc in a direct-current circuit-breaker with 6-in. break may be roughly estimated. When the carbons separate, the force for 10,000 amperes may be of the order of 3 lb. per inch, and when a loop of 3-in. radius

ing-current circuits presents no peculiarity except in machines and transformers where eddy currents may be set up in them, but above this figure "skin

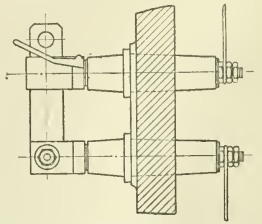


FIG. 29.—Typical isolating switch subject to large forces.

effect" has to be seriously considered. The skin effect in circular conductors admits of simple mathematical treatment. The figures for conductors of square

cross-section can be calculated approximately from the solution for cylindrical conductors. The case of a very wide strip conductor also admits of easy solution, and by interpolation between these results one can arrive at a fair idea of what happens in rectangular conductors as usually employed for busbars and heavy conductors, in the form of laminated bars with ventilating ducts between the laminations.

As to the thickness of lamination $\frac{1}{4}$ inch is a common and convenient dimension with $\frac{1}{2}$-in. ducts. With vertical conductors the ducts should be increased where practicable to $\frac{3}{4}$ inch. There is no benefit in building up alternating-current conductors of bars $\frac{3}{8}$ inch thick.

So long as the total thickness of the copper in the several laminations added together does not exceed $1\frac{1}{2}$ inches, skin effect does not become serious, but above this figure it rapidly becomes a most important factor.

Additional capacity can only be got by increasing the width of the bars in some way, or alternatively

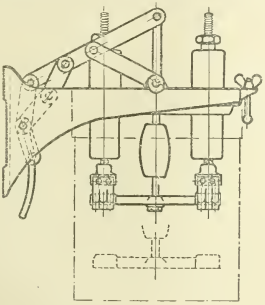


FIG. 30.—Typical oil switch.

by so arranging them that the inner and outer conductors are changed over so that each current stream flows through roughly equal lengths of inner and outer conductor. The bar should then be constructed of an even number of laminations, suitably separated by light insulation and space provided for the cross-over connection, which is not a very simple affair.

Where currents of the order of 5,000 amperes or upwards have to be or may have to be dealt with, it is therefore essential to provide ample room for the maximum width of strip which may be ultimately necessary and to keep down the maximum current to be dealt with, as for example by interleaving heavy incoming and outgoing circuits as in Fig. 8.

Stresses due to heating of conductors.—If a copper conductor is prevented from expanding and is then heated, it will exert a stress of about 240 lb. per square inch for each degree Centigrade rise of temperature. If the supports spring sufficiently to admit of expansion taking place, the stress will be limited to the amount necessary to spring the supports.

A copper busbar 10 ft. long and 2 sq. in. cross-section, able to carry, say, 2,000 amperes, will thus exert a theoretical maximum pressure of about 15 tons for a total temperature change, due to electric heating and atmospheric conditions, of 60 degrees C. This same bar for the same temperature change will increase in length by about $\frac{1}{8}$ inch. This can be absorbed by deflecting the bar about an inch at the centre if it is free to move, or by the slipping of the bar on its supports. Expansion is generally taken care of by slipping. It is, however, good practice on long busbars to limit this by the use of expansion joints.

Heating effects of large currents.—With the increase in the size of plant we reach limiting conditions due to heating effects, as we have on emergency conditions very high current densities to contend with. The heating effect being proportional to the square of the current quickly reaches abnormal figures. A plant may be quite safe against heating troubles and have perhaps a factor of safety of 4, but on doubling that plant the margin disappears.

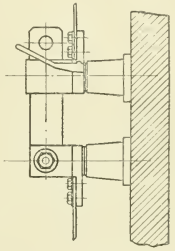


FIG. 31.—Typical isolating switching subject to small forces.

If heat is generated in a conductor very rapidly there is no time for radiation, convection, and conduction to play their part, and the heat is practically wholly absorbed in the conductor, resulting in a corresponding temperature rise. Currents flowing in copper conductors at 1,000 amperes per square inch will raise the temperature 50 degrees C. per hour if the heat is all absorbed. On this basis a current of 100,000 amperes, say 1,000,000 k.v.a. on 6,000 volts, will raise the temperature of a 0·1 sq. in. cable at the initial rate of about 12,500 degrees C. per second.

Under conditions which are permissible, the insulation on conductors does in fact absorb a considerable amount of heat and the theoretical maximum temperatures are not reached. For coils wound with wire or thin strip the rise may not be more than half the theoretical figure. On average underground cables the discrepancy would be something more like 10 per cent. Using this latter margin we get the following round figures for temperature rises:—

Density		Rate of Temperature Rise
10,000 per sq. in.		$1\frac{1}{2}$ degrees C. per second
100,000	,,	125 ,, ,,
200,000	,,	500 ,, ,,

The effect of these figures in practice will be seen by an examination of the round figures in the following table, giving the maximum permissible k.v.a. in a circuit for a current density limited to 100,000 or 125 degrees C. rise per second.

Cable	Maximum Current	k.v.a. at 6,000 Volts	k.v.a. at 20,000 Volts	k.v.a. at 30,000 Volts
Sq. in.	Amps			
0·025	2,500	25,000	85,000	125,000
0·050	5,000	50,000	175,000	250,000
0·100	10,000	100,000	350,000	500,000
0·250	25,000	250,000	850,000	1,300,000
0·500	50,000	500,000	1,750,000	2,600,000

The current values are R.M.S. values and the k.v.a. is figured three-phase.

The above figures give the initial temperature rise. The effect of the initial rise is, however, to raise the resistance of the copper conductors, the specific heat remaining steady so that the rate of rise is accelerated as it proceeds.

The serious overheating of a conductor in a cable may damage the cable from end to end.

Experience with stations designed in recent years and having a maximum short-circuit current of 10 times their normal rated output, has shown that it is necessary that the smallest current transformer on the main switchboard should have a carrying capacity not less than one-twentieth the station output. Current transformers of good design and much smaller than this have been known to be exploded by the heat generated on a short-circuit.

On one plant already existing in this country it has been found desirable to limit the cross-section of the smallest conductor to 0·15 square inch. The figures given above show clearly that in the large plants now in contemplation this feature will require careful consideration.

Discussion before The Institution, 7 March, 1918.

Mr. C. P. Sparks: Our industry for many years past has been faced, and is still faced, with continual progress. Going back 30 years, we experienced in a minor degree the problem which the author has brought before us to-night. I remember in connection with the early days of electricity supply in London, when I was working with Dr. Ferranti, as a result of increasing the size of the generating plant tenfold we found that the control apparatus and switchgear at substations and on consumers' premises began to give trouble. We were not then so well informed about these matters as we are to-day, and with the present growth of undertakings and the increasing size of generators, the subject which the author has dealt with is of very special importance to us all. We have known of these difficulties, but the author has now analysed them and shown how they should be met. For instance, he draws attention to the possibility of the burning out of comparatively large cables. In the early days we met with very much the same thing—the burning out of service cables when the undertaking reached a certain size. I entirely agree with the author in his remarks on page 271 regarding the use of reactance between busbars. The use of reactance in connection with feeders, however, must be limited owing to its effect on the regulation of the system. The use of high reactance in the electrical generators in these bigger developments is not difficult owing to the fact that the generator, with its step-up transformers, need be designed for only moderate regulation, with a view to adopting the most robust construction—as the author has pointed out—the transformer and generator as a whole being given any desired degree of reactance. Here we are assisted by another development, namely, the automatic regulator. It would be difficult to maintain satisfactory pressure when heavily fluctuating loads have to be dealt with if the automatic regulator had not been brought to the present degree of perfection, which allows us to maintain steady pressure even although the machine itself has comparatively poor regulating characteristics. I have experience of switchgear manufactured in various parts of the world and I can certainly bear out the author's remarks, towards the end of the paper, that the switchgear produced by British manufacturers and of British design has led the way. It is interesting to hear that from the manufacturer's point of view there are no insuperable difficulties in the design of bigger machines and switchgear able to cope with the larger forces which will have to be met in the future. That is to say, I understand from the author that the programme outlined by the Coal Conservation Sub-Committee is one that from the manufacturer's point of view is practicable so far as building these large generators, etc., is concerned. I have no doubt about it, but it is interesting to find that the manufacturers anticipate no difficulty in meeting the position.

Captain A. M. Taylor: I am, in the main, in agreement with the author's conclusions, but I think he has somewhat overstated the case for the use of reactances in the busbars—in so far at least as relates to the potential difference between adjacent sections. He has apparently modified his views about the amount of reactance to put between sections of the busbars. In a case that we jointly had under consideration some three or four years ago, the author himself—so far as I recollect—recommended 30 per cent reactance between adjacent sections, in order that in the event of a short-circuit on the middle section of a line of, say, three busbars, the current fed into this busbar through each reactance (i.e. at each end of the bar) should not exceed 25 per cent of the short-circuit current of the central section. This was for a ring system of busbars; and for a star system it would

be 15 per cent reactance. On referring to Fig. 24 it will be found that with 15 per cent reactance in the busbars only 0·15 of the load can be transferred from adjacent sections if the voltage rise is not to exceed 1 per cent. That is to say, on a 20,000-k.v.a. section only 3,000 k.v.a. could be transferred under working conditions, which is not enough. If the voltage were 10,000, even this would mean a difference of potential of 100 volts between the busbars. But to transfer half of the load would require something like $3\frac{1}{2}$ to 4 per cent rise of potential or, say, 400 volts between busbars on a 10,000-volt system, or 1,000 volts on a 25,000-volt system. The substations fed from different sections of the main busbars would therefore be at from 400 to 1,000 volts difference of potential among themselves and interconnectors would be impracticable, which takes away two or more stand-by cable connections from each substation. Another difficulty is with the generators. Suppose there are three busbar sections, each with its own generators, and that the central section, owing to irregular distribution of the load, is greatly overloaded. The two outside generators are arranged to supply current through the reactances to the central section at unity power factor. If the actual load has a power factor even as high as 0·8, there will still be a 60 per cent lagging component which has to be supplied by the central machine, and if the power factor of the load happens to be 0·6 it will be much worse. The central generator, therefore, is "overloaded" with magnetizing current and its power factor may easily fall to 0·6. This means that its current will differ in phase some 60 degrees from that of the two others, and if a short-circuit occurs there may be considerable phase-swinging, and even risk of its falling out of step. Fig. 17 shows sections of the busbars directly joined together by short-circuiting the reactances; but the author has forgotten to state that, if any adjacent pair of busbar sections be connected by trunk mains to an adjacent pair of busbar sections in a large station fed from the big station and having its own generating plant, the operation would result in considerable disturbance and involve risk of the burning out of the switchgear at the secondary station if a short-circuit occurred there at the time, because there would be too many kilowatts on an undivided section of the busbars at the smaller station. The author on page 272, line 20 from the bottom, says that the advantages in employing reactance in the generator are that (1) it is cheaper; (2) it does not hinder voltage control under normal conditions. With reference to the first, my recollection is that, in competition with that of another firm of certainly equal reputation, the machine with the external reactance came out the cheaper (including the reactance), and I was also informed by the builders that with still bigger machines the advantage would be increased. From the user's point of view I still prefer the greater security of the external reactance which can, in addition, be incorporated in the main busbar reactance chamber and then serves to protect the main cables (to the generator) and even the generator oil-switch itself. Consider the case where a large number of generators are on a busbar and one generator develops a fault to earth at a point (A) near one of the entering ends of the winding—the most likely place. If it be granted that a fault may develop at such a point it will also be admitted that a similar fault may equally be set up between another point (B) on one of the other entering ends of the winding and earth, owing to the sudden change in potential at the point B relatively to earth. This may, and would, happen before any trip-coil devices could act; and even if this point be challenged it cannot be denied that both faults might occur absolutely simultaneously. The great bulk of the winding of the machine is thus short-circuited, and there is nothing to prevent a tremendous current being fed back into the machine from the busbars, with disastrous results. An external reactance would stop this and, if put near the busbars, would save the cables, switch, and machine. With regard to the author's second point, I know of no voltage-control difficulties that do not apply equally to the two cases. I fully agree with his notes about the forces between conductors. I have seen a switch, like that in Fig. 30, which failed to open (through the current transformer failing) on a short-circuit just beyond the busbars, and the three available blades were all broken off by the repulsive forces of the currents (there being no arc). It was estimated that from 30,000 to 60,000 amperes flowed. Other, and more startling, results might be disclosed as to the effects of these forces; but sufficient has been said to show their magnitude. The great value of the reactance, as against any known form of switch, is that it operates in time to prevent the first half-wave of current from being generated. It is this first half-wave that does the damage to the windings of generators, etc. I have endeavoured to design a switch which will perform this same result, but with the advent of the reactance I feel that the question is largely solved, provided that the reactance can be relied on permanently. I believe that the B.T.H. reactances which are being put in at Birmingham will fulfil this condition. Feeder reactances, as the author rightly stated, are small—of the order of 0·5 per cent per mile. I refer of course to the inherent reactance of the feeders.

Mr. E. P. Hollis; I think that only those engineers who have seen big short-circuits can appreciate the immensity of the forces involved. I will mention three instances within my own knowledge. The first was a 6,000-k.v.a. set which was short-circuited; in a few seconds the station was filled with smoke, the switchboard could not be seen, and men had to be sent on to the roof to smash the glass to allow the smoke to escape. In the second instance the fault occurred near a switch, which completely disappeared except for molten metal. In the third instance a 20,000-volt dividing box failed, and the explosion was heard three miles away. One of the most difficult factors we have to deal with is the small consumer. If his main switch fails, the system will feed the same amount of current into the fault as if he were a 10,000-k.v.a. consumer. Looking at the problem as a whole, however, I do not think we are going in quite the right direction. We install a reactance which limits the short-circuit current. Now I think we are being misled by percentages. We originally made these proposals

for 5,000-kw. sets, and we are now using the same method for the bigger ones which are coming along. We have 50,000-k.v.a. sets being built in this country and 75,000-k.v.a. sets in America; and it will be found that the restricted value of the short-circuit current from these big sets is actually far greater than the unrestricted value from the small sets. Now we cannot insert more reactance owing to regulation and other matters, and so the problem arises: Is there not some way of introducing a protective device which shall limit the flow of short-circuit current, but which shall not affect normal currents? And I think there are such means. The next point I wish to consider is the question of the breaking of the current. To my mind it is quite wrong to break short-circuit currents on the switchgear. I think that when we start to design switchgear for the proposed large stations, its cost will be very heavy, it will occupy a good deal of room, and be very difficult to construct; and I believe we shall have to find some method of limiting the short-circuit current before opening the switch very much more than we do with the present reactances. Of course an attempt has been made to do this with a so-called reactance breaker. I think we shall have to consider more carefully in the future whether we cannot limit these short-circuit currents below the limits to which they are at present reduced by means of reactance coils. Personally I think that, as time goes on, the high-tension switchgear as we now know it will very largely disappear, and I do not think switchgear will develop on the present lines. I think we shall come to much more simple high-tension switchgear and a more effective method of reducing the current before the switch operates, if ever it is called upon to operate automatically at all.

Mr. A. H. Ellis: Several years ago reactance was considered to be anathema in electricity supply; now we are told to install it almost *ad lib.* The first suggestion came from those who studied solely supply phenomena; the second, from manufacturers. But does not the first suggestion still hold good, and is not the installation of reactance coils merely *camouflage* for protecting faultily-designed apparatus? However, be that as it may, in any large cable system the capacity effect is the greatest, and if we go on adding inductance in the shape of reactance coils, when and where ought we to stop? The author gives, generally, the amount of reactance, and where to connect it to give the greatest protection, but he says nothing about the frequency of the supply. The author again says there is no unsurmountable difficulty—meaning, I take it, commercially—in designing machines, switchgear, etc., for meeting the increased stress. Then why add reactances? It is said that by adding reactance the disturbance is localized. But is it? I know of a station of 50,000-k.v.a. capacity that had reactance, but when a machine broke down the switch failed to open properly, the resulting arc spread over the whole switchgear, and in less than two seconds the whole station was one mass of flames and had to be shut down for several hours. In another very large station a current transformer did the same thing, yet a short-circuit across the busbars cleared itself. Yet both stations were protected with reactance, and it certainly did no good in localizing the trouble in those instances. In fact we can never really tell where a fault is going to stop, although we may suspect where it will start. Another point with these breakdowns is that notwithstanding all the latest protective relays, they are made inoperative owing to the control wiring being burnt up. As regards putting reactance in the generator, there is a limit to this in two ways: (1) to increase it beyond a certain point raises the cost of the machine; and (2) it will be found that a large turbo-alternator with heavy inherent reactance completely loses its voltage on a violent short-circuit, this being a serious matter where synchronous apparatus is concerned. Hand control of the voltage is also almost completely ruled out with such machines, owing to the large margin of field current required for a small variation in load. My experience with reactance has not been altogether satisfactory, and before adding further apparatus which is itself liable to break down and increase the cost and lay-out, we should very carefully consider whether other methods cannot be economically adopted before committing oneself to the use of reactance. I cannot see what the author hopes to gain by stopping up the pressure for a 3-mile distribution. It seems to me only to add other weak links to the chain, for, as the author himself says, "the total number of disturbances to which a system is subjected increases automatically with each extension." Can he give figures showing that apparatus is more immune from breakdown at 20,000 volts than at 6,000 volts, or in cost of cable against cost of transformers and equipment for stepping up and down? It may possibly be found, after running some of these super-stations, that the large powers cannot be satisfactorily controlled. However, I think the author has written an extremely interesting paper, which shows minutely what large forces are brought into play when a fault does occur on a large system, and bringing into relief the care that should be exercised in selecting only first-class material to be used thereon.

Mr. A. G. Collis: I should like to call the author's attention to Fig. 1 on page 273, which shows the instantaneous rise of short-circuit current with and without reactance. Will he please explain how the figures were obtained, as they do not appear to agree with other tests. If an alternator is short-circuited, the instantaneous rise of current is limited by the characteristics of the machine, and is generally calculated at 30 times normal. How far this is correct can be judged by the following figures. Mr. Diamant, in a discussion on a paper I presented to the American Institute in 1915, illustrated a curve of short-circuit current. On a 12,000-k.v.a. 9,000-volt 25-period turbo-alternator the instantaneous current rise was between 30 and 40 times full-load current, the machine having the following characteristics: resistance 0·04 per cent, reactance 6 per cent. It may be of interest to note the comparative example. If by applying 5 per cent external reactance the instantaneous rise of current is 17·1 times normal, or otherwise if 3 per cent reactance and 1·2 per cent resistance be introduced, the maximum current would be 17·3 times normal, or about the same

if 5 per cent reactance be inserted. One is well aware that low-speed sets generally have higher reactance than high-speed sets; the instantaneous currents therefore are thus proportioned. Again, on a 6,000-k.v.a. alternator with a 4 per cent reactance the instantaneous current rise on test was 18 times normal. Referring to the author's curve (Fig. 1) the k.v.a. rupturing value of the switch is hardly affected whether we have reactance or not. Assuming that the switch broke the current in 0·5 second, the short-circuit current as given in this figure is $2\frac{1}{4}$ times normal, as against $1\frac{1}{2}$ times normal with reactance. Fig. 3 appears to be a far more efficient method of distribution than that shown in Fig. 4. There are many points against reactance in series; these are well known, so they need no reference here. The k.v.a. capacity at the end of a feeder can easily be limited to a predetermined value without resorting to reactances as shown in Fig. 3, and in connection with the same the reactance and impedance must be added vectorially to get the impedance drop at this end of the feeder. The use of reactances to limit the initial current rise is the chief consideration as applied to generators, and, in this, one forms the conclusion that the further use of reactances is chiefly governed by the localization of energy in proportion to its distribution, that is, the grouping of sections of energy so that the effect of a fault on any section does not affect the total kilovolt-amperes of the supply. Will the author please explain the curves illustrating the comparative value of reactances. The motor-operated switch shown in Fig. 7 appears to be very complicated and cumbersome. Possibly the author will give us some more particulars of this switch, and mention the time it takes in opening and closing circuit, which is an important matter. Engineers appear to be divided into two camps—those who prefer a quick-acting switch and those who desire the switch to follow maximum disturbances. First, all are agreed that the switch should close quickly for the purpose of synchronizing. No provision appears to be made, however, for a "half-cock" or synchronizing position; if this is not correct, what arrangement is made for fool-proof operation? Secondly, the figures which the author gives prove it is essential to open circuit rapidly. A motor-operated switch occupies more time in opening than those of the solenoid pattern, therefore the value of reactances is much reduced. Again, in Fig. 30 another form of switch is shown fitted with wedge contacts. Are these considered to be a better form of contact than the brush for medium conditions? Fig. 27 illustrates a current-limiting reactance. Failing a full description of this, what is the author's opinion of this method of reducing short-circuit currents? Does it necessarily mean the elimination of iron from such coils? There appear to be advantages and disadvantages in either case. The question arises whether the introduction of iron in reactance coils might possibly in certain cases offer sufficient advantages to offset the disadvantages, such as the practical elimination of stray magnetic fields and the reduction of short-circuit current by I^2R losses.

Captain J. M. Scott-Maxwell: The engineers of one of the largest power stations in America have developed an extra-high-tension fuse which has been widely used in the States for many years. This high-tension fuse is capable of breaking a short-circuit on a system up to 110,000 volts and with a fair generator capacity behind it. I have oscillograms showing this fuse on a 110,000-volt system, connected between the star point and one line or across 66,000 volts; there were three generators, I think, of 9,000 k.v.a. each on the line, and this fuse opened the circuit in one half-period. The inventors of the fuse claim that it almost invariably opens the circuit in a half-period, whereas the quickest-acting oil switch takes more than four periods. By using these fuses to protect outlying circuits, their very quick action localizes the fault at once. One speaker has mentioned that he did not think the high-tension switch would develop along the present lines. It may be possible to parallel an oil switch by means of one of these high-tension fuses, so that under ordinary switching conditions, or probably on safe overloads, the fuses would be first disconnected and the oil switch used to open the circuit. On short-circuits, which may damage the oil switch, the latter would be opened first and the fuse actually clear the line. These fuses have very high rupturing capacity, but it is difficult to get a high current-carrying capacity and so they are best suited for small feeder circuits or circuits of high potential when a high value of k.v.a. is possible with low amperes.

Mr. J. S. Highfield: There are just two points I should like to deal with in connection with this paper. The first is this. Several speakers have indicated that there should be simplification of the switches and gear, and I am quite certain that all the work that can be done in that direction is time well spent. Nothing is so important as to simplify the power-house gear. One of the first essentials is a switch that will open circuit with perfect certainty and great speed. Some years ago in connection with the late Mr. Duddell I tried a series of experiments with switches based on the principle that one cannot maintain an arc between two metal contacts when the pressure is less than about 500 volts. As a matter of fact, we kept the pressure down to about 250 volts per contact. The contacts consisted of metal discs of about 2 in. diameter with a rough surface, and we built up a string of these and arranged so that they would open successively—just a little opening of about $\frac{1}{8}$ inch or less. We found that the switch working on a 1,000-volt 600-k.v.a. turbo-alternator opened the circuit under the most severe conditions with the greatest success without any oil being used. We were getting on well, and then we discovered when we applied for a patent that one of the firms in this country had a German patent which exactly covered this device; it has always surprised me that it has never been used. My other point is this. I have lately been very much up against the great difficulty there is in distributing the current after it has left the power station, especially from overhead lines carrying very high powers when it is desired to tap off rather small currents from these lines. The cost of tapping off a 20,000-volt line is quite considerable, and the amount and cost of gear which has to be arranged between the 20,000-volt line and the consumer

is nearly as great for the 50-kw. consumer as for the 1,000-kw. consumer. In farming and agricultural districts it is most desirable that the farmer should be supplied with cheap electric power, but all he wants is perhaps 20 kilowatts. Now there is no cheap way of tapping that power from a 20,000-volt line and I hope the author will direct his attention to that problem.

Mr. F. H. Clough: I should like first of all to confirm the author's statement that it is quite possible to obtain 20 to 30 per cent reactance in modern generators. This being so, it does not therefore seem necessary to use any reactance in series with the generator, especially as the inherent reactance can be obtained without detriment in any other direction. High-reactance generators of course have naturally a poor inherent regulation, but with large power stations the diversity factor of the load is such that close inherent regulation is not important, and in any case automatic voltage regulators are available, which will maintain the voltage sufficiently constant for all practical purposes. In considering the important point of continuity of supply, it would appear desirable to put the reactance in series with feeders. But if alternating-current distribution is used, any such reactance in series with feeders tends to reduce the possible area over which reasonably constant voltage can be maintained. It therefore seems desirable to keep the feeders as far as possible of comparatively small size, so that if a fault occurs on one of them the amount of current flowing is not sufficient to disturb the main busbar voltage to any great extent. If large feeders are necessary, then probably reactances must be used in series with them, and in that case it may be necessary to have synchronous machinery at the far end of the feeder by which the power factor of the feeder can be varied, or else to use static feeder boosters.

Mr. A. R. Everest: At the foot of the first column on page 275 the author points out that in the event of certain precautions not being taken, "the alternative course will result not in immediate disaster, but in a gradual lowering of the factor of safety until serious trouble points to the cause and necessitates a far more costly remedy." The author has suggested it is desirable in these large plants that the smallest current transformer used on the system shall not have less than a specified fraction of the total capacity of the system. I think the general subject of lowering the safety factor of the entire plant by the introduction of inadequately designed accessories is really worth discussion in itself. When we come to these big plants that are being discussed, the importance of these matters becomes very great. There is one other point which I should like to mention, namely, the "reactance", that is referred to here so often. Various speakers have referred to reactance and I am not quite sure they all mean the same thing. The reactance referred to by the author is that which limits the currents on sudden short-circuit to certain values. For this purpose a 10 per cent reactance is that which on sudden short-circuit at full voltage allows 10 times normal full-load current to flow, and no more. Such a reactance if it contains no magnetic path liable to saturation would show a reactive drop of 10 per cent of the machine voltage when passing normal full-load current. But if there are magnetic paths which become saturated when heavy currents flow, the reactive drop if measured with relatively small currents, such as those flowing under ordinary working conditions, would indicate a much larger percentage reactance than would be actually available under the short-circuit condition of heavy currents and the associated magnetic saturation. This is a condition to be guarded against.

Mr. J. H. Sandiford: Most of the previous speakers have dealt with the advisability or otherwise of the reactance in different parts of the circuit, and whilst it is a matter of opinion, perhaps, whether reactance should be added in a generator circuit or in a feeder circuit, I think we are all unanimous that with the large amount of running plant that is or will be connected to the busbars, reactance will be necessary between the various sections of the busbars, and I think very great consideration should be given to the design of the actual reactances themselves. At our last meeting the paper * dealt with the standardization of switchgear, and I think the question of reactances is one that should be gone into as it is such a very simple matter and could be standardized very quickly. The reactance shown in Fig. 26 is built of concrete, which is not, I think, the best material; it is apt to absorb damp. This particular type of reactance is to be installed, it is suggested, in a brick chamber. To my mind the reactance body could be better built of porcelain, which could be extended round the outside without interfering very much with the ventilation. In that case it would not be necessary to go to the expense of placing the reactance in a separate chamber; it could stand in any convenient place near the switch-gear cells. I think this is a matter that might be given consideration. Then, again, the copper conductors appear to be bare, but I think there is likely to be trouble in that respect, as the bare conductor will attract dust, and breakdowns between the end terminals may occur. My point is that if such a large number of reactances are going to be installed in the near future, with such large installations as are in view, I think it is a very favourable time to go into the question of standardizing them.

Mr. L. Andrews (*communicated*): Whilst the author clearly shows the necessity of inserting artificial current-limiting reactances in large power circuits, one feels, nevertheless, that finality has not yet been reached in any of the proposals put forward. To procure partial protection against faults, which are only likely to occur at comparatively infrequent intervals, by introducing a permanent fault into the system which—as the author points out—"interferes with the regulation to an extent which may be quite serious for lighting," is possibly the lesser of two evils, but it surely cannot be considered to be a solution of the problem. I should like to ask the author whether he has considered the use of discriminating or balanced-current reactances as a possible solution, that is, reactances which are comparatively non-inductive on normal load but become highly inductive on a short-circuit to earth or between phases. Reactances having these charac-

* See page 213.

teristics were described in a paper on "The Arrangement and Control of Long-distance Transmission Lines," read before the Manchester Local Section in 1903 by Mr. E. W. Cowan and myself.* The system then described was the origin of the balanced-current method of protecting duplicate feeders, and was used for a time with complete success for this purpose, but was subsequently superseded by the Merz-Price balanced-current and pilot-wire system, which is a development of the same principle. The balanced-current devices referred to (both the Merz-Price and my own) depended for their sense of discrimination upon the direction of the flow of energy, which is not possible in reactances used as described by the author, since the direction of flow under normal conditions and under short-circuit conditions is, or may be, the same. It would appear, therefore, that discrimination in such cases must depend upon the magnitude of the current only. I suggest the following adaptation of my original balanced-current reactances as a possible solution of the problem:—In place of the straight series reactances, described by the author, discriminating reactances are used constructed with two windings, whereby the current in the first or primary winding is balanced and thus rendered non-inductive by an induced current in a secondary winding short-circuited through an excess-current circuit breaker. In the event of an abnormal rise of current occurring in the primary winding, the corresponding excess current in the secondary winding would instantly operate the excess-current circuit breaker, thereby interrupting the secondary current and leaving the primary winding to act as a straight series reactance. If these balanced-current reactances are constructed without magnetic leakage, the ampere-turns in the secondary circuit will balance the primary ampere-turns at all loads, with the result that the reactance will be entirely non-inductive until the secondary circuit has been interrupted. Such construction would not limit, in any degree, the first rush of current that would be liable to occur before the secondary circuit breaker opened. It would appear to be desirable, therefore, to construct the reactances with sufficient inductance, due to magnetic leakage, partially to limit the first rush of current, which inductance would be greatly increased by the opening of the secondary circuit. The use of balanced reactances would tend to eliminate the difficulty of constructing switches for controlling large powers. This difficulty was most aptly described by the author, in the discussion on Mr. Beard's paper† as endeavouring to "stop Niagara in a tank 2 ft. × 2 ft. × 4 ft." Many other speakers have referred to this difficulty in recent discussions, and amongst the various suggestions which have been made for dealing with it, there have been proposals for increasing the number of points of break either by multiple contacts in series or in parallel. This remedy is entirely dependent upon all points of contact being broken simultaneously, a condition which it is almost impossible to ensure with any appreciable number of contacts. Should one of the contacts open half a cycle earlier than the others in the case of series contacts, or half a cycle later in the case of parallel contacts, the leading or lagging contacts respectively will have to break the entire load. The balanced-current reactance system, described above, ensures that the short-circuit current will be broken at as many points as there are reactance coils, and provides that each circuit breaker does its proper share of the work of checking the flow of energy, even though there may be a delay of one or two complete cycles between the operation of each breaker. Furthermore, should one of these circuit breakers fail to interrupt its arc, it may be immediately short-circuited by a simple section switch, without materially impairing the action of the other protective devices in series with it. The scheme proposed is illustrated diagrammatically in Fig. A herewith. It is assumed that it has been decided to provide for a maximum reactance in series with the circuits corresponding to a 10 per cent drop at normal full load, that the maximum permissible drop to secure reasonably satisfactory regulation is 2 per cent on full load, and that the safe breaking capacity of the circuit breakers is one-fifth of the maximum short-circuit current of the system. For such conditions, five

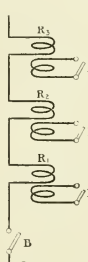


FIG. A.—Balanced-current reactances and switches for controlling short-circuit currents of any magnitude.

balanced-current reactances should be connected in series. Each reactance should have a full-load drop of 2 per cent with secondary circuit open, and a magnetic leakage drop of 0·4 per cent with secondary circuit closed. A series circuit breaker with time-element attachment to delay its action until all of the secondary circuit breakers have completed their work, would finally break the reduced short-circuit current. With such a system it is merely necessary to divide the reactances into a greater number of sections, to be able to control with safety the heaviest short-circuit current imaginable.

Mr. D. E. Bailey (*communicated*): On page 277 the author states, with reference to the parallel running of alternators, that it has been found to be not generally practicable to obtain stable running conditions where the ohmic value of the total reactance in circuit between the machines is less than about twice the resistance.

* *Journal I.E.E.*, 1903, vol. 32, p. 901.
† *Ibid.*, 1916, vol. 54, p. 229.

I shall be glad to know if the reactance and resistance referred to are those external to the machines and do not include the machine reactance and resistance.

Dr. G. Kapp (*communicated*): The paper deals mainly with the protection that is given by current-limiting reactances and, as far as lines and current-consuming devices are concerned, such reactances are in our present state of knowledge the only means available for this purpose. It might perhaps be thought that a very great improvement in the construction of automatic circuit breakers, enormously increasing their rapidity of action, would form an alternative method of protection, but this is not so. Even if it were physically possible to construct a self-acting switch which would break the circuit within the first two or three periods after a short-circuit has occurred, this would only mean transferring the danger of destruction from the apparatus to the switch. The switch would have to open with a current 15 or 20 times its normal value, and it is obvious that no switch of normal rating could stand this. As a matter of fact, switches do not open instantaneously, so that if used for the protection of synchronous generators there is some lowering of the electromotive force actually induced in the machine by the time the switch opens, but the reduction may still be insufficient and the current at the moment of break be still too large for the switch. Hence the necessity either of adding some true reactance outside the machine or of providing it inside. In Fig. 5 the author shows a total reactance of 14 per cent in machine and transformer, so that the first rush of current will be about 7 times the normal value. Since the switch does not open at the very first cycle of the short-circuit current the demagnetizing action of the armature current will reduce this figure somewhat, but the duty thrown on the switch is nevertheless very severe. By making the reactance larger we reduce the danger to the switch, but we make the regulation worse. Reactance in feeders and service lines is necessary for their protection and for that of the consumers' apparatus, but here we are faced with a new difficulty, namely, the reduction in the power factor of the system as a whole. As in most engineering problems we are thus forced to make a compromise between conflicting conditions. The arrangement shown in Fig. 4 seems a good compromise, as it affords fair protection to all parts without unduly reducing the power factor. This advantage is obtained by grading each reactance with regard to the particular circuit it serves. Thus if a fault occurs on a consumer's circuit the particular reactance Y will limit the current and allow the switch to open without itself being destroyed, whilst the lowering of the voltage on the whole system due to a large current passing for a moment through the reactance X will not be excessive. Protection of plant outside the power house will thus be generally possible, but the problem becomes more serious as regards the protection of generators. It is in this respect that I here put forward a suggestion for the author's criticism. Throughout the paper he deals with synchronous generators. A machine of this kind must not only be provided with additional reactance (whether inherent or external) but a switch must be used of a rating much in excess of its maximum service k.v.a. capacity. In Fig. 9 the author even shows that two such switches should be provided for each machine. An external reactance will in most cases be necessary. It is quite true that the machine and transformer may be designed to have any desired reactance, but there is a practical difficulty which one also encounters when designing a large reactance coil with an iron core. No difficulty exists in small coils with narrow plates and a moderate number of ampere-turns in the coil, but in a large apparatus of this kind not only are the ampere-turns producing the flux through the air-gap very large, but the core plates are wide and become heated by the leakage lines squeezed out transversely to the surface. To some extent this also happens in a generator or transformer designed for large reactance, so that quite apart from the convenience of being able to use standard apparatus, the soundness of the policy of providing what the author calls "inherent reactance" seems doubtful. We may therefore take it that the set consisting of generator and step-up transformer will have to be provided with a reactance coil of the kind shown in Fig. 26 containing no iron. The use of a synchronous generator therefore involves the use of (1) a large and bulky reactance coil, and (2) an automatic oil switch of extra large rating. If now the synchronous machine were replaced by an induction generator no external reactance at all would be required, and the oil switch would even in the case of a dead short-circuit on the busbars only have to break a moderate current. With two switches for each generator, as the author suggests, this means a material reduction in cost and space. Thus far the use of asynchronous generators would appear to be an ideal solution of the problem of protecting generating machinery, but there is a disadvantage if we use asynchronous machines of the usual induction motor type. Such a machine takes its exciting current from the busbars. Some synchronous machinery is therefore required to fix frequency and voltage. This machinery must work at a bad power factor, because it has not only to supply the wattless component of the load current, but also that of the asynchronous machines. Fig. B will make this clear. Let two machines, the one synchronous and the other asynchronous, of the same kilowatt capacity be supplying a load of 0·8 power factor. The power factor of the induction machine is taken as 0·9; it gives the current O A. The current required by the load is twice O S. If both machines were synchronous each would have to give the current O S at 0·8 power factor, but as one machine is asynchronous it not only fails to give its own share of the wattless current, but it takes from the other machine also the current A B, so that the synchronous machine will have to give in addition to its fair share of wattless current B S, the additional current A S, making the total wattless current drawn from it B T, and its k.v.a. capacity instead of being proportional to O S (which would be the case if all machines were synchronous) is proportional to O T, that is about twice as great. It is obvious that such a system is impracticable, because the increase in cost and the reduction in efficiency in the synchronous part of the plant would far outweigh

any gain resulting from the suppression of reactances for the asynchronous part of the plant and the cheapening and simplification of its switchgear. It is quite possible, however, to make such an equipment practicable by using asynchronous generators which have a leading phase angle. Low-speed induction motors have been built with a natural slip of about 1 per cent at the full load of about 1,500 h.p., and judging from this there should be no difficulty in building a 20,000- or 25,000-kw. turbo induction motor with a natural slip of $\frac{1}{3}$ or $\frac{1}{4}$ per cent. With the high speed, large power, and few poles there will be no difficulty in designing such a generator for a natural power factor of 0·9 or more; and if such a machine is fitted with a phase advancer of quite moderate dimensions it can generate current with a power factor of 0·8 or even 0·7 leading, and be able to supply a load having a lagging power factor of equal value without any help from synchronous machinery other than fixing voltage and frequency. A 100,000-kw. power house might then be equipped with two 25,000-kw. synchronous machines and four 25,000-kw. asynchronous machines. This would give the two spare sets the author considers necessary, and it would only require two extra heavy sets of automatic switches and two reactance coils. The switches for the asynchronous machines may be rated for only 25,000 k.v.a. each, and no reactance coils would be required for these machines. Moreover, the synchronizing apparatus and the switchgear in connection with it would be restricted to the two synchronous machines, resulting in a considerable simplification of switchgear generally. Asynchronous machines are cheaper and lighter than synchronous, so that the cost of the whole equipment would be less. It might be objected that the four phase advancers are an additional complication and involve additional outlay, but this is a very small matter. With the small natural slip of such a generator the number of kilowatts required for excitation would only be about one-third of that required for the synchronous machines, so that on the four sets 2,000 kw. would be saved in exciting machinery. Whatever type of phase advancer be used, it is important to reduce as much as possible the losses in slip-rings and connections, and the ohmic losses in the advancer itself. This means that the rotor should be wound for a much higher voltage than is customary in induction motors. There is no objection against a high-voltage winding in the rotor, because the machine is a generator and is never used as a motor. In a motor the stator is switched on whilst the machine is at rest and the starting resistance does not prevent the full open-circuit voltage to earth being developed at the slip-rings before the machine has got under way. With a generator the case is different. The machine is only connected to the busbars after it has been run up to speed, so that whatever might be the slip-ring voltage of the machine at starting if used as a motor, when running as a generator it need not exceed a few hundred volts. There is no difficulty in insulating either slip-rings or the winding of the rotor for this voltage. The possibility of the machine being put into circuit whilst at stand-still is as remote as that of a synchronous machine being switched on whilst standing or running unexcited and need hardly be guarded against, but such a contingency can easily be provided for by some interlocking arrangement. The author shows in Figs. 26 and 27 the general shape of a reactance coil. It is in the matter of proportions an improvement over the thin disc coils first used some years ago, but the proportions are not those which give the greatest k.v.a. capacity for a minimum amount of copper and a minimum ohmic loss. A 10-per cent reactance coil for a 25,000-kw. machine would have to be rated as a 2,500-k.v.a. coil, and nothing less solid than a cement framework can serve as a support, but this need not prevent the coil being proportioned for maximum plant efficiency, i.e. maximum duty with minimum copper. Maxwell has proved mathematically that the best coil is a toroid with a mean diameter 3·22 times the diameter of the circular cross-section. For such a coil the inductance in henries is * $L = 9{\cdot}35\, n^2\, D \times 10^{-9}$, where D is the mean diameter in cm. and n the number of turns. A coil of circular cross-section is impracticable. We must for facility of manufacture use a coil of rectangular cross-section and preferably a square section. For a square of the same area of the circular section of Maxwell's toroid the inductance is practically the same, and if the departure from the square is not too great (say, sides in the ratio of 1 to 2) the reduction

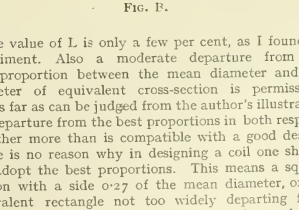


FIG. F.

in the value of L is only a few per cent, as I found by experiment. Also a moderate departure from the best proportion between the mean diameter and the diameter of equivalent cross-section is permissible, but as far as can be judged from the author's illustration the departure from the best proportions in both respects is rather more than is compatible with a good design. There is no reason why in designing a coil one should not adopt the best proportions. This means a square section with a side 0·27 of the mean diameter, or an equivalent rectangle not too widely departing from a square. The following formulæ may be useful in the calculation of such reactance coils. Let D be the mean diameter of the coil given in metres, s the space factor, q the cross-section of the conductor in sq. cm., Δ the current density in effective amperes per sq. cm., and $\omega = 2\pi \times$ frequency, then the inductance in henries is $L = 0{\cdot}5\ (s/q)^2\ D^5$; the weight of copper contained in the coil is $W = 2{\cdot}17\ s\ D^3$ kilograms, the volt-ampere choking effect is $V\,A = 0{\cdot}5\ \omega\ (s\ \Delta)^2\ D^5$, and the plant efficiency (or volt-amperes per kilogram) is $V\,A/W = 2{\cdot}3\ \omega\ s\ (\Delta/100)^2\ D^2$.

* G. KAPP: "Principles of Electrical Engineering," p. 212.

It is of interest to compare the constructive features of an asynchronous and a synchronous generator of the same power. The following table contains data of design for the two types:—

12,000-KW. GENERATOR.

1,500 r.p.m., 50 periods, cos $\phi = 0{\cdot}8$, *line volts* = 11,000.

	Synchronous	Asynchronous
Slip, per cent	0	0·5
Slip-ring current, amperes	710	660
E.M.F. between slip-rings	150	68
Exciting power used in rotor, kw.	106	40
Weight of exciting copper, kg.	2,450	1,650
K.v.a. of phase advancer	—	78
Loss in phase advancer, kw.	—	9

It will be noticed that the slip is extremely small, notwithstanding that the amount of rotor copper is appreciably less than in the synchronous machine. Apart from the saving in cost, there is the incidental advantage that the centrifugal force on the end bells is reduced by reason of the reduced copper weight of the winding. The open-circuit slip-ring voltage is 16,000. This may be thought an inadmissibly high figure, and to a designer accustomed to think of an induction machine always as a motor an impossible suggestion. Yet it is quite safe. In a motor one seldom likes to go higher than 600 to 800 volts, and that for a very good reason. A motor must start itself. At the moment of switching on, this voltage is actually impressed on the slip-rings and no amount of starting resistance can alter this condition. A generator is started by its engine and only switched on when at full speed; but then there is very little slip and the slip-ring voltage is enormously reduced. The only point to be considered is how close the engine must govern so that the slip-ring pressure shall not exceed the 600 or 800 volts considered safe for an induction machine. Without going too closely into the vector diagram we may take it that roughly 1 per cent slip produces 160 volts, so that an error in the governing of 4 per cent would be permissible. There is no difficulty in obtaining a governor to regulate the speed closer than 4 per cent, but if desired all danger can be avoided by interlocking the switch with some centrifugal device (in addition to a visual indicator) which will prevent the handle being moved except when the speed is within, say, 2 or 3 per cent of the correct value. It is of scientific interest and also of practical importance to inquire as to the mode in which generators will share the load in any given case. To get a clear conception I take as a starting point a station equipped entirely with synchronous machines. Load and power factor are supposed to vary but slowly, so that the excitation can be adjusted to meet any load condition. The author has assumed a power factor of 0·8 at the busbars; this means a higher power factor than 0·8 at the consumer's terminals. Such a condition may be attained if some devices such as condensers or dynamic phase advancers are used to improve the power factor of consumers' loads, and it will be the easier attained the heavier the load; but as a general proposition we must be prepared to find the power factor at the busbars rather lower than the author has assumed, and especially if the station is on light load. I think it will not be unduly pessimistic if we assume that at light load the power factor at the busbars is as low as 0·6, nor unduly optimistic if we assume that it is as high as 0·85 at full load. The vector representing the total current sent out from the station will therefore lie somewhere between the lines O a and O b in Fig. C, which lines form with the busbar volt vector O B the angles whose cosines are 0·6 and 0·85. Let O L be the vector of the current for any particular load condition, then the point L must for any load condition between minimum and maximum load lie within the trapezium shown in the figure. As, however, the natural condition of working is high power factor with heavy, and low power factor with light load, the actual locus of L is not the area of the whole trapezium, but only a

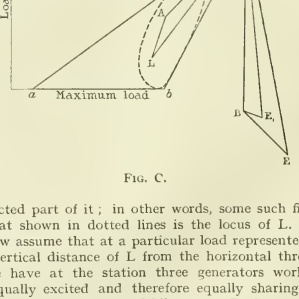


FIG. C.

restricted part of it; in other words, some such figure as that shown in dotted lines is the locus of L. Let us now assume that at a particular load represented by the vertical distance of L from the horizontal through O we have at the station three generators working, all equally excited and therefore equally sharing the load both as to current and kilowatts. Each generator gives one-third of the total current O L, and works with the same power factor. Any change in general load and general power factor can be provided for by simultaneously changing the excitation of all three machines. But there is also another possible way of regulating. We may supply a little more than one-third of the total power to each of two machines and keep their excitation constant, doing all the regulation necessary on the third machine only. In Fig. C let O A be the current vector of the two machines; then the current vector of the third somewhat more lightly loaded machine will be A L. If O B is the busbar voltage, then O E is the voltage to which each of the two machines must be excited. B E is in quadrature and proportional to O A. In the same way B E_1 is in quadrature and proportional to A L. If the condition of supply change so that L assumes some other position within the locus curve, we may readjust the excitation of all three machines so as to suit the new condition, but if the

change is not great we may leave the two machines in their vectorial relation O E B and only readjust the excitation of the third machine, which means readjust the vectorial position O E_1 B. Now let us see how the problem stands if the two machines doing the greater part of the work are asynchronous and only the third machine is synchronous. Whatever type of phase advancer be used, the locus of the end of the vector of the stator current for two machines (that is the current delivered to the busbars) is a curve of the shape shown in Fig. D. Curve P_1 corresponds to maximum busbar volts and such adjustment of the advancer as will produce maximum effect and curve. P_2 corresponds to busbar volts at light load and adjustment of the advancer for a reduced effect. The busbar voltage is fixed by the requirements of the service (higher for heavy and lower for lighter loads), but the advancer can be adjusted so as to make the P curve pass through any point such as A corresponding to a particular power supplied by their engines to the asynchronous generators. We now have these machines in the same condition as the two synchronous machines in the former case (Fig. C), and here, as there, the third and

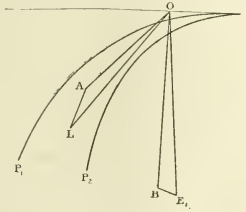


FIG. D.

synchronous machine is merely used to make up the total current O L by supplying the component A L. By regulating the excitation of the synchronous machine we can, as before, adjust the plant to slight changes in total load and general power factor, and it will be seen that the working is stable even if we do not adjust the phase advancers. For let the load slightly increase. This calls for a slight increase of busbar voltage, and that is obtained by exciting the synchronous machine a little more, which can conveniently be done by an automatic regulator. A higher busbar voltage causes the P curve, which (though not shown in the figure) formally passed through A, to shift a little to the left. A is thus shifted to the left and a little downwards because of the greater load. At the same time that the synchronous set takes a higher load due to the increase of its excitation the asynchronous sets also take a higher load. The ratio in which the total load is shared between the two types of machines need not therefore be greatly altered. It is always possible to throw the bulk of the load on to the asynchronous machines by adjusting the advancers so that A shall lie as nearly as possible on the line O L, and the contribution of the synchronous machine to the total power need not be more than one-third or one-quarter of the total load.

Mr. M. Rosebourne (*communicated*): As mentioned by the author the advantages offered by reactances may be enumerated as follows: (1) The strain on the oil circuit-breakers is limited; (2) the disturbance on the system due to a short-circuit is limited and synchronous apparatus is prevented from falling out of step; (3) the short-circuit current is limited, and overheating and damage due to the large electromagnetic forces involved are thus prevented. Where the busbar system is divided into a large number of sections (the number depending on the size of the station) the necessity for transference of power from one section to another depends largely on the size of the units connected to each section, as this determines the number of spares which could be economically kept. Where the system is large, necessitating, say, four sections, each section having, say, two units each of 15,000 kw., it would not be economical to have spares for each section, and thus in the case of a breakdown of a unit on a section it will be necessary to transfer power from the other sections through the reactances coupled to these sections. This, we may take it, will be the general practice in all new propositions, as, from an economical standpoint, large units undoubtedly present the most favourable aspect. In the above case the reactances should be designed so as to carry the maximum transferred kilovolt-amperes continuously, as well as the short-circuit conditions momentarily (i.e. during the period of the operating of the oil circuit-breaker clearing the fault, with the necessary additional safety factor). In this connection I should like to ask the author whether he considers it satisfactory normally to short-circuit the reactances by oil circuit-breakers possessing direct-acting series instantaneous overload trips arranged so as to operate in an absolute minimum of time. By this means the cost of the reactances would be greatly diminished, as they would then only have to withstand the momentary short-circuit conditions and would be normally short-circuited. With this arrangement, of course, the whole station would be solidly connected together without reactances during the period required to operate the circuit-breakers short-circuiting these reactances. The time required to open these switches would be of the order of 1/20th of a second, and being series-tripped they would be arranged to operate before the feeder circuit-breakers, which would be relay-operated. During this period (1/20 sec.) during which the maximum short-circuit current will flow, it will be necessary for the system to withstand the large current involved, and to ensure that the voltage has not dropped to such an extent at the end of this period that synchronous and other apparatus connected to the system would not be affected, assuming the worst conditions of a fault on or near the busbars. I think this system has been employed in practice and I should like to hear the author's opinion about it. If one studies the vector diagram involved during the transference of load from one section to another, it will be observed that the transfer of a load of high power factor leads to a large angular displacement between the voltages

on the sections; and as the power factor of this transferred load is reduced, thus increasing the output of the sets connected to the section to which power is transferred, this angular displacement is diminished, but the difference of voltages between the sections increases. These two factors, i.e. phase angle and voltage difference of sections, have to be considered under load-transference conditions, and their values depend on the reactance inserted between the sections. In large systems it is very necessary to see that all connections and apparatus will withstand the maximum short-circuit current during the period required to isolate the fault, such examples being current transformers, cables connected to auxiliary sets, step-down transformers, feeding auxiliaries, etc. This last point is often overlooked, and quite small cables are installed where circumstances call for much larger sections.

Mr. E. B. Wedmore (*in reply*): During the preparation of this paper I have been in communication with Mr. Phillip Torchio, chief electrical engineer to the New York Edison Company, and Mr. R. F. Schuchardt, electrical engineer to the Commonwealth Edison Company, and they have sent me a quantity of valuable and interesting information largely confirmatory of the conclusions reached. The following extracts will be of interest.

Mr. Phillip Torchio writes:—"There is in service in the Detroit Edison plant a 45,000-kw. unit, and I understand some 50,000-kw. units are on order. With the increased size of generators, the reserve capacity should also be larger, and we have therefore felt that the 35,000-kw. units were about the right size for our system, especially in view of the fact that very little saving in economy is effected by installing units larger than this. The internal reactance of the largest generators that we have on order has been about 16 per cent, and in addition to this we planned to install external reactors of approximately 6 per cent. I see no objection to having a combined external and internal reactance of the generator as high as 20 to 25 per cent, and with the increased size of stations this value will certainly reduce the stresses occurring under short-circuit conditions. Generators operating on a common busbar with reactances as high as 25 per cent should give no difficulty. However, with the installation of busbar reactance, the total amount of reactance (including busbar and generator) should be below 50 per cent, especially on conditions where there is a very fluctuating load. With this reactance above 50 per cent the generators may fall out of step, due to a very rapid change of load, and in one case this has occurred. For the particulars of this I would refer you to Mr. Johnson's paper before the American Institute.* In extra-high-voltage lines, where possible, we think it is more satisfactory to perform the switch operation on the low-tension sides in place of the extra-high-tension side of the transformer The main objection to switching on the high-tension side of apparatus (where this can be done on the low-tension side) is that in any switching operation high-frequency surges are set up. These surges, of course, are very much more severe when the switching is done under air than under oil; but under either condition the high-frequency surges, which usually result in high-potential strains, occur. When the switching is done on the low-tension side of the transformers the surges are not so apt to pass through the transformer to the high-tension side of the apparatus. In our limited space conditions, the ring design comes out more economical than the star where a complete duplicate busbar arrangement is desired. The star arrangement requires a synchronizing as well as a feeding busbar, and consequently with a complete duplicate system there would be required four busbars, two synchronizing and two feeding, whereas a ring system requires only the two busbars. I feel that the greatest amount of protection can be obtained by the use of feeder reactors, as the largest amount of trouble experienced is due to feeder troubles, and, in addition, the operating conditions are more satisfactory. With feeder reactors ranging around 3 per cent, the short-circuit current is naturally limited and well within the rupturing capacity of modern switches. I would not recommend, except under special conditions, a busbar reactance greater than 40 per cent based on the full-load current of the busbar section. Further limitations are based upon the amount of current that is to be transferred from one section to the other and the conditions of the feeder circuit. These latter two conditions are usually the limiting features. The use of busbar reactors in localizing disturbances is of considerable importance, and if the reactance can be made of sufficient amount to hold the adjoining busbar section to, say, 50 per cent voltage under short-circuit of a section, considerable saving will be effected by not having synchronous apparatus drop out of step on these accompanying sections. Where stations are tied together through feeders offering ohmic resistance, we figure that the amount of reactance should be between $1\frac{1}{2}$ and 2 times the amount of resistance to maintain the busbar in stable condition. We have not experienced any difficulty with parallel operation in cases where the reactance is at least 1·73 times the resistance. This is based on a constant resistance with the reactance varied. This was made up in this way as the resistance between synchronous units is usually definite, and the amount of reactance to be placed in the circuit can be varied at will. Of course, the ratio of reactance to resistance is not the only determining point in stability, and we figure that the maximum synchronous torque which can flow over the tie lines must be at least twice the maximum possible fluctuation in load at either point. We have figured that the installation of feeder reactance coils increased the stability of the rotary converters, and these converters on long feeders are usually the ones to first drop out of step on any system trouble. In the generating station, outside of the potential transformers, which are connected by fuses, we have found it necessary not to put in too small a section of conductor no matter what capacity of unit is tied to it. Generally speaking, we tried to hold this section to at least 250,000 circular mils for preventing overheating under short-circuit conditions. This pertains to stations of 50,000-kw. capacity and above. We think it desirable

* *Proceedings of the American Institute o Electrical Engineers*, 1917, vol. 36, p. 119.

to clear the short-circuit from the busbar as quickly as possible and, with automatic relays, have attempted to bring this time down below 1 second. The quicker the trouble is cleared the less the chance of serious trouble developing."

Mr. R. F. Schuchardt writes:—"Reactance is desirable for limiting the current which will flow in the event of a fault. On the system of the Commonwealth Edison Company, 60-cycle generators of 14,000-kw. capacity have approximately 7 per cent inherent reactance, and those of 30,000-kw. capacity approximately 13 per cent. The total reactance, internal plus external, of the 25-cycle units is 8 per cent for the 12,000 kw. to 13 per cent for the 35,000-kw. units. The external coils should have a reactive value from 2 to $2\frac{1}{2}$ times the resistance value for satisfactory parallel operation. Where the busbar voltage is 6,000, it would seem preferable to have the generators wound for this pressure rather than to use step-up transformers. Where such transformers are used they should be designed to have a reactance approximately that of external reactance coils, which would otherwise be employed. Such transformers should also be designed to have time-temperature curves similar to those of the units to which they are connected. Under certain conditions of underground distribution, potential rises are less when the switching is performed on the low-voltage side of the transformers. They may make separate operation of the transformers desirable. Sectionalizing of busbars is desirable but should not be carried too far. Whether or not the reactances should be used depends on the particular conditions of each case, but where they are used tie switches shunting them should be provided so that at times of light load the number of sections may be reduced in order to obtain more economical operation. The choice between the ring and star designs will be determined by the local conditions. Each has some advantages. The number of sections shown, however, seems rather excessive. Personally, I would rather put the money into a higher factor of safety in the general construction of the electrical connections and busbars than in the larger number of reactors. Since the maximum economy of the transmission system is obtained by fairly complete interconnection, that is, with lines in parallel, a multiplicity of sections divided by reactors introduces serious complications and limits the full use of the transmission investment. The busbar connections of our Fisk-street and Quarry-street stations follow the ring design. The greater stability is obtained when the reactance value of the tie feeders is from 2 to $2\frac{1}{2}$ times the resistance value of these same feeders. To obtain this value often requires the insertion of reactance coils. The hunting or pulsation of synchronous converters which you term 'phase swinging' may be caused by excessive voltage variation, by improper ratio of reactance to resistance, or by excessive load variation. This refers to modern systems where the supply is from turbo-generators. With reciprocating engines, hunting is often set up by irregular angular velocity in the prime mover. The only apparatus in which the cross-section of the conductors requires special consideration is the instrument transformer on apparatus the capacity of which is comparatively small with respect to the system to which it is connected. A case in point is the motor-driven exciter in the generating station. If the instrument transformers on such a unit were of a size conforming to the apparatus to which they are connected, as is generally the case, the energy flowing from the station busbars into a possible fault in the step-down transformers of the exciter units might be so excessive that the instrument-transformer wiring would be fused before it could operate on the protective device. A special instrument transformer having the necessary ratio but with a primary winding very much larger than usual should be employed in such connection. In general, the cross-section of the conductors in apparatus should have a safe margin for normal operation, and all protective apparatus should have a safe margin for abnormal operation, that is, for the conditions which arise during faults."

Mr. Torchio and Mr. Schuchardt have not yet had an opportunity of reading the paper, but the above comments have a direct bearing on the issues raised and are self-explanatory.

Mr. A. M. Taylor has referred to some recommendations I prepared five years ago for a scheme in which he was interested. There were five busbar sections and he quotes the reactance as 30 per cent. This figure was, in fact, the carrying capacity of the reactance in terms of the section capacity. The reactances were to have an ohmic value of 20 per cent, which on the ring design corresponds to about 10 per cent on the star design. Now, on referring to Fig. 24 we find that with 10 per cent busbar reactance and 30 per cent transfer we have a potential difference of $1\frac{1}{2}$ per cent. This figure would be reached only when transferring the full 30 per cent load at 80 per cent power factor, i.e. under conditions not calling for extra magnetizing current from the machines feeding the assisted section A carrying capacity of 30 per cent on a closed ring coresponds to about 60 per cent on a star system, so that these recommendations agree very closely with those in the present paper, written after an interval of five years. In a similar case I am now recommending about $7\frac{1}{2}$ per cent for the star reactance, but with a higher generator reactance than was contemplated five years ago.. Mr. Taylor has quoted a method of connecting stations which would lead to serious consequences and which I have not dealt with. It is a case excluded by my recommendations. I quite agree that with reactances within or external to the generators the voltage-control problem is substantially the same. The contrast intended to be made was with reactances in series with the feeders. The figures given by Mr. Taylor for the short-circuit currents which damaged a switch of the type shown in Fig. 30 suggest that the switch was subjected to short-circuit stresses much above those for which switches of this general design are commonly intended.

Mr. Hollis has given us an Impressionist picture of the generating station of the future, with details of what will not be employed. The problem is one which has to be solved this year, and I have shown that this can be done with apparatus already designed and

proved in service. Nevertheless, in the light of future developments we shall probably consider our present methods crude and complicated.

The broad conclusions and the recommendations in the paper do not depend upon frequency. The figures quoted for inherent feeder reactance do of course vary with frequency, and I am indebted to Mr. Ellis for drawing attention to this. The frequency taken was 50 periods in each case. With increasing concentration of load, the economical voltage for a given radius of distribution rises rapidly, and the radius I have used for 20,000 volts in the example referred to by Mr. Ellis is not much less than has been figured for smaller stations than I contemplate. In such a case, if Mr. Ellis omits the transformers, the use of reactances becomes not merely desirable but an imperative necessity.

Fig. 1 referred to by Mr. Collis is based on a comparison of a number of recent machines of different makes and may be taken as typical of recent practice. The switch shown in Fig. 7 needs no description. It is to be found in almost every large generating station in this country. Fig. 30 is inserted to show a particular arrangement of conductors, and many working details are omitted, including the sparking fingers. The main contacts shown are of the controller type, and within the limits admitting of their use it is well known that they will withstand much worse treatment than any brush contact. They will operate properly even after the sparking contacts are destroyed.

Several designs of high-tension fuse have been developed of high rupturing capacity suitable for use in large generating and substations in small circuits, such as auxiliary circuits, and where first cost is a primary consideration they may be so employed, but are not so convenient as oil switches. There is room for them also in overhead line distribution to small consumers, where first cost is always important. The suggestion of shunting an oil switch with such a fuse is not new. It is very similar to the idea of shunting a large fuse of small rupturing capacity with a small fuse of high rupturing capacity. Both schemes have similar limitations. On a bad fault considerable voltage appears across the small fuse and therefore across the larger device, and the latter may not clear within the time allowed by the former.

Mr. Highfield makes a demand, with which we must all concur, for more engineering. In connection with the developments now before us there is almost unlimited scope for engineering, and their success will be in proportion to the attention given by technical experts. At the present time trained engineers have to spend too much time supervising untrained assistants. There is an urgent need in the national interest—to put it on no higher level—for an increase in technical education through continuation schools, scholarships, bursaries, and in other ways. It may be said that technical engineers are mostly overworked and under-employed.

Mr. Sandiford advocates the employment of a porcelain-clad reactance, and suggests that porcelain is a better material for the structure than concrete. I think there can be no two opinions as to the relative merits of the mechanical characteristics of the two materials. We sacrifice these and use porcelain where we need high resistance to electric stress. This is unnecessary in reactances having dimensions such as are usually required for the purpose in view. I have already given good reasons for not totally enclosing the structure, and it appears to me that one could not regard the porcelain as a safe protection against shock except on moderate voltages. I anticipate the Home Office would require the structure to be installed in a place set apart for the purpose. The design illustrated is one which has been employed on a number of large installations with uniform success.

The system of reactance-switching described by Mr. Andrews is not new in its essential details.* As a means of assisting the switch such schemes have very limited application. As a device for relieving the system it operates too late. The use of reactances with large mutual induction in parallel feeders has the disadvantage that it is dependent upon both feeders being in service. They can no longer be considered independent feeders. The reactance coils in series with them must be in intimate relationship.

In reply to Mr. Bailey, in one case investigated experimentally with a wide range of resistance and reactance values, it was found that the generator reactance and resistance should be included to get consistent results. Some of the available records are not very clear. If the generator reactance is included, the ratio 2 : 1 may be found a little on the low side. The recommendations made and variety of reasons given by engineers whom I have consulted show that we have not yet reached finality.

Dr. Kapp suggests the extensive employment of self-excited asynchronous generators as an alternative solution to the use of reactances. I am not clear that he has established his case. We have still to consider the question of relative cost of the commercial designs which would be required. We have to consider what characteristics it is necessary to give to the synchronous and asynchronous sets to ensure that, in fact, on a fault developing, the asynchronous sets shall not give out a large amount of power. It is known that these machines are capable of doing so (see, for instance, a paper by Messrs. Spooner and Barnes in the *Electrical World*, 24 February, 1914). Suppose, however, that a satisfactory solution is found and it proves that we can employ just such a combination as is suggested by Dr. Kapp; what have we got? We have limited the fault currents without the use of certain reactances, but the omission of these reactances has left us with a system the whole of which suffers on a severe fault occurring anywhere in the neighbourhood of the generating station or principal substations connected to it. It should be understood that the use of reactances is not only commercially advantageous in limiting stresses on the distributing system, but exercises a very valuable effect in maintaining voltage by the isolation or partial isolation of faulty sections. Where synchronous substation machinery is employed it is important to employ generating plant which will maintain the voltage during a disturbance and not die down quickly. The successful operation of the

* See Patent 8571 of 1905.

plant will be dependent upon the synchronous generators and there must be an adequate provision of spare synchronous machines. If the busbars are sectionalized, synchronous sets must be available for each section. It is, however, quite practicable to employ machines such as Dr. Kapp advocates, and we are indebted to him for bringing out certain possibilities of their use. I do not quite agree with Dr. Kapp's remarks on the duty of oil switches required with synchronous machines. We have to obtain oil switches not only able to deal with the output of individual machines, but with the combined output of all the running machines which may feed in parallel into a fault. Thus on a generator failing, its switch may have to open a circuit in which the current is several times that which the individual machine could give out, and the same remark applies to feeder faults. In the design of reactances economy in the use of copper and in copper losses is not the principal consideration. A coil to replace Fig. 26 designed on the basis of Dr. Kapp's suggestions would occupy considerably more floor area and would have a much higher voltage between turns than is suitable, whilst the economy in copper would not be great. Dr. Kapp suggests that in taking 80 per cent power factor I have been too liberal, as this figure will not be reached on low loads. We are concerned with the maximum magnetizing currents which have to be transferred through the reactances, and these are reached only at full load. The relative values may be greater at low loads but the maximum cannot be.

Mr. Rosebourne refers to the use of busbar reactances inserted by switches operating in, say, 0·05 second. Such an arrangement exercises no limiting action on the maximum stresses and could only be employed where these were not a limiting feature. From the standpoint of reliability on emergency it is sufficient to compare the number of parts that go to the making of a high-speed automatic oil switch of large rupturing capacity and its control gear with those employed in a reactance.

Western Local Section, 11 March, 1918.

Mr. H. I. Rogers: In connection with the Interim Report of the Coal Conservation Sub-Committee, of much greater immediate importance to the nation than the saving of coal is the securing of cheap power. Cheap power means more machinery, and more machinery means higher wages, because a greater output can be obtained from the worker. Perhaps the most serious question after the war will be how to keep wages up to anything approaching the present level, bearing in mind the probable cost of commodities. The sooner the community realizes the absolute necessity of an entire change in our methods of electric power distribution the better.

Mr. S. F. Walker: I would ask, in connection with the Report just mentioned, why need we stop at 16 sectional stations? Why not have overhead and underground busbar systems receiving current from every possible generating station in the Kingdom and delivering current to everybody who wants it. Why not deal with every source of power that we can get and deliver it all to one system? There is a lot of water-power in the Highlands of Scotland, and there is no reason why we should not get some of it. All the heat which is going to waste in our iron-works, steel furnaces, gas works, etc., could be harnessed and delivered to such busbars.

Mr. H. F. Proctor: I feel that I should like to discuss the paper this day 12 months. I would point out, however, that there are many people who have fallen into an error in construing the Interim Report of the Coal Conservation Sub-Committee. The Report does not suggest that there should be 16 generating stations only, but that the country should be divided into 16 generation areas. There may be half a dozen stations in each of these areas. The Report was only issued a month or two ago to the public, but the suggestion for 16 areas was put forward by the Linking-up Committee some 18 months ago. Mr. Walker has mentioned the utilization of other sources of power. The use of waste heat from blast furnaces is suggested in the Report, and that our generating stations in the future will not be merely electric generating stations but stations having perhaps gas and all other works for by-products. The only difficulty will be to know which is the by-product and which the main product.

Mr. W. A. Chamen: I begin to see a question arising as to whether, under certain circumstances, it is right to put down one large generating set to deal with a certain output, or whether it should not be subdivided. It is a point that requires most careful consideration. The author says that in modern practice where the midpoint of the system is earthed, all faults to earth will be cleared without serious voltage disturbance, and the large majority of cable faults are of this character. It happens that we have just had trouble with a resistance on an earthed neutral, and I was rather hoping that as we have now put reactances in circuit with each of our alternators there would be no need for continuing the use of such resistances. I had hoped that we had got rid of the necessity for putting any resistance in the earth connections at all, but the author does not apparently support that.

Mr. W. Nairn: So long as the distribution system is sound there is no difficulty in dealing on the network with the 100,000 k.v.a. which the author takes as his typical station output, the difficulties only arising when a fault occurs on the system. I suggest that the matter of primary importance is to have reliable protective gear installed which will disconnect the fault as speedily as possible, the reactances having only a secondary duty, viz. to stem the rush of current to the fault until the protective gear has done its work. It is therefore of interest to consider the classes of network faults which may occur and how far it is possible to obtain protective gear to clear them. The faults are of two classes, first those which occur on the mains or overhead lines, and secondly those which occur on switchgear or busbars in the substations and are com-

monly referred to as busbar faults. Thanks to the valuable research work which was carried out on the North-East Coast, we have the Merz-Price and Merz-Hunter protective systems which may be safely left to take charge of faults of the first class, but when we come to deal with busbar faults we are faced with a more difficult problem, and I know of no protective gear which will prevent such faults being thrown back on to the power-station overload relays. At the foot of column 1 on page 278 the author certainly mentions the use of fixed time-limit relays with graded settings, but I am satisfied that such relays are useless outside the power station for clearing such faults and it would be most interesting to know how the author proposes to install them on, say, a simple ring main. If then, as I believe, such faults cannot be cleared locally, it follows that busbar faults will shut down the entire network until located and cleared by hand, and I suggest to the author that the question of busbar faults is another of the limiting factors in the extension of super networks. I believe that to ensure a reliable supply it is necessary to divide the network into rings of reasonable capacity not solidly linked together, and if power is to be interchanged between power stations of large size it should be done through separate trunk feeders and not through the network. In the footnote on page 270, column 2, the author gives the size of the individual units for a station with 50,000 kw. output, viz. one 50,000-k.v.a. unit, and three 25,000-k.v.a. units, the 50,000-k.v.a. set being used when available. I consider this would make a most unsatisfactory station, as in my opinion it would not be safe to handle such a large load as 50,000 k.v.a. with only one set running. A fault on the set or even a minor defect on the auxiliary plant might shut down the set, and when we consider that the capacity of this one set is capable of handling the present-day maximum demand of a city like Manchester, we can form some idea of the inconvenience which would be caused. I would not consider that less than three units of suitable size should be used on such a load, so that if one were to drop out the remaining two units would at least maintain an impaired supply until the spare machine was switched in. The particulars given regarding reactances are most valuable, and whilst their installation in generator circuits and in busbar sections is no doubt justified, the difficulty of pre-determining the current on extensive networks will, I feel sure, prevent their extended use in this position. The question of whether the reactance on the generator circuit should be external or internal is for the designer of the machine to settle, and as soon as makers cease attributing breakdowns of generators to faults on the external circuits, so soon will power-station engineers be only too pleased to dispense with the external reactance. The paper is full of most interesting controversial points, and in conclusion I should just like to ask the author the size in current-carrying capacity of the largest three-phase 500-volt automatic oil switch now available. The question is of interest in connection with the installation of large banks of transformers required for low-pressure work which will be protected by Merz-Price gear.

Mr. I. A. D. Pedler: I gather from the author's remarks that he is not favourably disposed to the installation of impedance coils actually in the conductors of the feeders transmitting load under normal conditions. Would he consider it practicable to install such impedance coils in the conductors of separate feeders provided that they are normally short-circuited with an oil switch, the maximum cut-out of which should be devoid of any time limit, so that in the event of a rush of current due to a fault the oil switch would open immediately, giving the desired choking effect as afforded by an impedance coil before the rush of current rises to its maximum? I think this question depends entirely upon the time limit of the cut-out under the conditions of fault prevailing at the time at the operating end of the faulty apparatus.

Mr. E. B. Wedmore (*in reply*): I understand that Mr. Chamen would like to earth the mid-points of the generators solidly, so as to eliminate the earthing resistances. I think the better course is to increase the factor of safety in the design of the earthing resistances, which, after all, are very simple devices. If the earthing resistances are omitted, every fault near the source may become a dead short-circuit on at least one phase, so that we have to deal with maximum stresses and maximum disturbances of current flow. One can design to avoid faults between phases by the use of specific devices and arrangements, but one can only design against faults to earth by increasing the factor of safety all over, which is a much more costly procedure.

I quite agree with Mr. Nairn's estimate of the importance of the use of discriminating protective apparatus on large systems. The best way of dealing with busbar faults is by designing against them. Mr. Nairn recognizes that from this standpoint everything on the busbar side of the oil switches, including even the oil switch terminals, is part of the busbar system. What is wanted is thorough isolation of phases from the oil switches to the busbars proper. In important stations, therefore, each three-phase switch should preferably be constructed of three single-pole units with terminals sufficiently separated to allow of barriers between phases.

I have not suggested the use of 50,000-kw. units except in neighbourhoods requiring several large interconnected stations.

I do not think that the difficulty of pre-determining current values will hinder the use of reactances. Their use generally sets a pretty definite limit to the short-circuit currents.

Switchgear is obtainable suitable for medium-voltage circuits up to 6,000 amperes and extra-high-tension circuits up to 1,000 amperes. Neither figure is final in any sense.

The use of reactances inserted automatically has been suggested before. They cannot be made to limit the first peak value of the current and it is this value which determines the maximum stresses.

Manchester Local Section, 12 March, 1918.

Mr. G. A. Juhlin: The author has given certain values of the short-circuit current, but has not made it clear exactly what these values mean. For example, in Fig. 1 two curves are given, one representing the current in the case of a dead short-circuit and the other the current on a short-circuit limited by reactance. The maximum short-circuit current indicated by the curves is 10 times the normal current. It is not clear whether the author has considered a symmetric or an asymmetric short-circuit. If the latter is the case, the values appear to be too low. It seems essential that some definite basis should be laid down in giving these values, for if manufacturers are asked to state short-circuit currents and one gives the R.M.S. values and assumes a symmetric short-circuit, whereas another gives the maximum possible peak value, we should have the latter approximately 2·5 times as great as the former, assuming the machines in question to have the same reactance. In connection with the general use of reactance, it appears that the author has dealt with the question solely from the point of view of reducing the stresses which may fall on the generators or any other apparatus on the system. There is another aspect which I think should be borne in mind when considering the value of reactance as a protection for generating plant. It serves to minimize the concentration of voltage on the first few turns of the winding caused by high-frequency surges with steep wave fronts which may occur on the system. In so far as stresses on the windings are concerned, there is no need for reactance coils in order to protect the generator when the machines are of moderate voltage. Generators of 30,000 k.v.a. capacity for 6,600 volts are being installed without reactance and guaranteed to withstand dead short-circuits. When dealing with high-voltage machines running at 10,000 to 11,000 volts the installation of reactance is to be recommended, not so much from the point of view of stresses on the winding as for the protection of the end turns from surges. As the protection of the stator windings is of importance, it may not be out of place to deal with the question of faults discussed by the author on page 278. While I agree that it is not at present possible to limit faults between phases, as in the case of faults to earth, we have at least protective gear which will cut out apparatus that has failed between phases. The most common cause of trouble with generators and transformers is failure between turns. This is the general experience in this country, as well as in America, but we are still without means of cutting out either a generator or a transformer which may happen to develop a short-circuit between turns. The author mentions the separating of the conductors of a machine over their whole length, including the end connectors, with an earthed metallic shield. Earthed metal shields have been employed on the slot portion to prevent static discharges, but I am of the opinion that it would be very difficult to extend this scheme to the end connections on account of insulation difficulties, and it seems doubtful whether it would materially reduce the risk of destruction by fire, as the time required to establish a destructive arc is exceedingly short. Several instances could be mentioned where machines have been totally destroyed by fire, although the faults which occurred were extremely small. The fact that the faults were very small could be judged from the amount of copper which had been fused. It is undoubtedly of great importance to protect machines from destruction by fire, and in this connection it may be of interest to mention a scheme which has been brought out with this aim in view. It consists of providing dampers in the air ducts of the machine, which can be tripped automatically by the Merz-Price or any other protective gear that may be installed. The air supply would then be cut off immediately a fault occurs in the generator and thus prevent the total destruction of the winding by fire. In dealing with the effect of voltage disturbances on synchronous machines, the author expresses the opinion that rotary converters will not be disturbed if the voltage drops to 50 per cent of the normal. This appears to be optimistic, especially in the case of 50-period machines which are naturally more sensitive to phase-swinging than 25-period machines. Further, it would seem necessary to consider the question of the general arrangement and load of the system before accepting such a figure, as the voltage drop is given at the source and may therefore vary at different sub-stations depending on the load on a particular feeder. The author states that the influence of running machinery on the short-circuit current is relatively small. This is probably true in most cases in this country, but I believe there are cases where the running machinery will materially affect it, especially when it is considered that the running machinery may feed into the fault without any reactance in circuit.

Mr. A. E. McKenzie: I think the author is right in stating that for some few years to come we shall have to content ourselves in this country with generators of 20,000 and 30,000 kw. capacity. Such sizes are contemplated for the new Manchester power station, and it is the intention there to use step-up transformers and to do all the switching on the extra-high-tension side. When the station was first contemplated, the question of installing switchgear on the low-tension side was considered, in addition to switchgear on the high-tension side, but it was the general opinion of the experts at that time that to control a 150,000-kw. station at anything less than 20,000 volts was almost an impossibility because the switchgear would be altogether too heavy. I think those engineers who are controlling stations of 50,000-kw. capacity at the present time will be in agreement with that view. Regarding the inherent regulation of large generators, I think we have all modified our views in recent years as to the necessity for fine regulation. In the old days when the traction load greatly exceeded the power and lighting load, the momentary fluctuations were such that it was quite necessary to have machines with fine regulation. To-day the power load dominates to such an extent in most large stations that the momen-

tary variations in the load are negligible, and machines having coarse regulation and short-circuit currents of comparatively low value are preferred. Automatic voltage regulators will be found quite unnecessary, as switchboard attendants can regulate the voltage by hand as the load rises or falls. We do not fear to-day faults to earth, either on generators or on feeders—our protective gears should adequately safeguard us against all such faults. The worst faults are those between phases in proximity to the main generating station. Faults on generators invariably start between turns of the same phase winding, and then go to earth before developing between phases. Every generator should be protected by balanced protective gear, with the addition of a device for disconnecting the main field immediately the main switch is opened. I am not in agreement with Mr. Juhlin as to the necessity for automatically closing the air dampers on the outlet and inlet sides of generators. I agree with him that dampers should be provided, but I think it undesirable to add further complications to the protective gear by having them automatically operated. The author rightly calls attention to the necessity for sectionalizing distribution systems. This is not an easy matter, particularly when the mains are laid on the ring system. In Manchester we were rather fortunate in having had our mains originally laid radially, and it was therefore easy to divide the system into three almost equal parts. The two outer sections are loaded approximately to 27,000 kw. each, and the central section to 21,000 kw. The short-circuit currents are respectively 32,000 and 34,000 amperes. A fault on the middle section would be 10 per cent worse than on either of the outer sections. A demand in the near future of 75,000 kw. is anticipated at Stuart-street station, and by the installation of 20 per cent reactances in the busbars a load of 75,000 kw. will be more safely dealt with than one of 50,000 kw. was without them. I was sorry to hear Mr. Juhlin disapprove of the suggestion put forward by the author for the earthing of the end windings of generators. It occurred to me immediately I read it that it was exactly what we were looking for—something that would put the winding to earth when a fault occurred, instead of allowing it to develop between phases. I hope that generator designers in general will look upon the suggestion with more favour than Mr. Juhlin has done. Regarding the employment of selective protective apparatus, the author rightly suggests the provision of a second line of defence. At Stuart-street station there are six groups of feeders, two groups on each section; each of these groups controls 10 feeders through a main group switch. During the last 10 years only in three or four cases has one of these main group switches operated, but I have no hesitation in saying that if it had not operated there would have been a severe switchgear breakdown on each occasion. About three months ago a short-circuit across the terminals of an oil switch in a substation quite close to the generating station caused the feeder oil-switch at the latter place to operate. Through a screw having worked loose, the switch opened very slowly and an arc was maintained across the switch contacts. Fortunately, the group switch then opened and cleared the fault from the busbars. The standardizing of the rupturing capacity of oil switches certainly should be taken in hand. Purchasing engineers know that manufacturers offer switches widely differing for the same duty, and unless detailed drawings are supplied the best switch is often passed over on price. As to the best method of installing reactances between busbar sections, I certainly prefer the star system to the ring. The former necessitates an additional busbar, but it has the advantage of enabling any section to be taken off at will without interfering with the remainder, and this alone is a decided recommendation. The design of reactance illustrated in the paper seems a good one. It is made wholly of non-combustible materials, it is easy to inspect, and if provided with good insulators at the base there seems to be no reason why any faults should develop upon it. I am in thorough agreement with the suggestion that expansion joints should be provided in the main busbars. During the last few years I have seen many large insulators broken and much trouble caused through the lack of these. The author refers to one plant where it had been found desirable to limit the cross-section of the smallest conductor to 0·15 square inch. This is most important on large systems. Such limitations are very necessary if trouble is to be averted. Most small current transformers are—in the event of faults—frequently called upon to carry loads beyond their safe capacity, and explosions occasionally result.

Dr. W. Cramp: For the sake of brevity I will group my criticisms of the paper under 11 heads:—(1) The term "reactance" is used almost throughout the paper in a wrong sense. It is misleading, for instance, in the footnote on page 273 to refer to a reactance as "wasting energy." Obviously the author means "impedance," and he ought not to confuse terms which have definite meanings in this way. Where he wishes to refer to the apparatus itself as distinct from its function, he might use the term "choking coil," "choker," or better "impedance coil." (2) The principles upon which the values given in the paper are arrived at need explanation. Apart from impedance coils inserted in divided busbars the author considers many cases in which he seeks to protect long circuits. Now it would appear from sections III and XII that he contemplates the use of selective protective apparatus as well as impedance. Under these conditions the purpose of the impedance is to limit the rise of current until the protective gear has had time to act, and thereafter to keep the current down to such a value as the oil switch can safely deal with. If this be correct he should consider maximum currents and instantaneous conditions; whereas he seems to assume only R.M.S. currents and steady conditions. (3) Even on the assumption of steady conditions and R.M.S. currents the calculations of the author are misleading, especially in cases like that illustrated in Fig. 4, where the distance X Y may be several miles. He neglects entirely the effects due to capacity, self-induction, and leakage of the line. It is well known that the current entering a cable on no load is $E/Z \coth \theta$, where E is the applied potential difference, Z the surge impedance, and θ the hyperbolic angle of the cable. If now the

distant end of the cable be earthed, the current will change to $E/Z \tanh \theta$. The steady short-circuit current therefore depends largely upon the relationship of $\coth \theta$ to $\tanh \theta$, and this ratio may be anything from unity to a very high value. Thus to calculate the effect of inserted impedances without regard to such an important factor seems to be somewhat rash. (4) The important function of the impedance in enabling the oil switch to open the circuit was illustrated by Mr. Partridge* in the oscilllograms he gave in the discussion on the paper by Peck and Faye-Hansen, and again by Professor Marchant in his recent paper.† It is, however, neglected by Mr. Wedmore, although it is of great importance in deciding the amount of impedance desirable. (5) Fig. 1 is unconvincing unless the author can give the exact conditions to which it refers, when it might be of very great use. It is to be hoped that he will do this in the *Journal*. (6) I should be glad if the author would explain the footnote on page 276 and the paragraph to which it refers. It is not clear to me why one current should necessitate a greater potential difference at the terminals of a given coil than another current of the same value and frequency. (7) The author makes statements concerning the absolute reliability of oil switches which are not I think borne out in practice. Besides the case referred to by Mr. McKenzie, many of us have experience of the failure of oil switches; often I am sorry to say through lack of attention to detail in design. (8) In connection with Fig. 26 I would draw attention to the fact that the author gives no particulars relative to the design of ironless chokers, and it appears to me that the design illustrated is the American type referred to by Peck and Faye-Hansen. The proportions do not appear to me to be those which would secure the maximum reactance with the minimum amount of copper. The coil appears to be too long, and I should be glad if the author would tell us how it is designed. With regard to the use of chokers containing iron, has the author ever considered the possibility of a core with an air-gap so arranged that when the current exceeded a pre-determined figure the gap would close and a much larger reactance be automatically put in circuit? Also has he any knowledge of the use of Hilliard's switch which on the occurrence of a short-circuit puts a choker into operation? (9) The busbars recommended by the author contrast sharply with the standards recommended by Dr. Garrard in his recent paper.‡ (10) Finally, as a result of the four years which have elapsed since the reading of the paper by Peck and Faye-Hansen very little progress seems to have been made. It is true that Mr. Wedmore seems to have revised the figures that he gave in the discussion on that paper as suitable values of the reactances to be used, but as he gives no results of experience during the four years and no details of design the information contained in the present paper carries us but very little farther than did the previous authors. The general discussion of the various possible positions for the impedance is, however, of particular interest at the present time.

* *Journal I.E.E.*, 1914, vol. 52, p. 522.
† "Some Transient Phenomena in Electrical Supply Systems."
‡ See page 213.

Mr. J. Denham: The point that I particularly wish to bring out is, what is the number of kilovolt-amperes actually broken in an oil switch relatively to the kilovolt-amperes produced by the generator? For instance, when a short-circuit occurs and an oil switch cuts off the fault, it is not correct to assume that the number of kilovolt-amperes broken by the switch is the same as the instantaneous short-circuit kilovolt-amperes delivered from the generating plant to the fault. For example, assume a generator having 10 per cent reactance (internal or external) and connected with an oil switch, provision being made whereby the switch terminals on the side remote from the generator can be short-circuited. Assuming that the resistance of the circuit is negligible compared with the reactance, then the instantaneous short-circuit kilovolt-amperes of the generator will be 10 times normal full-load. This, with normal voltage, means 10 times full-load current, and with this current flowing the generator voltage will be absorbed entirely by the reactance, leaving no voltage at the actual short-circuit. Assuming the switch to be fitted with an overload trip, then just as the contacts are on the point of separating the kilovolt-amperes at the contacts are zero, since the voltage is zero. When the switch has fully opened and the current is broken, full voltage exists across the switch contacts, there being no pressure drop in the generator reactance as no current is flowing. Thus the kilovolt-amperes at the contacts are zero when the switch is fully open, because, although full voltage exists, there is no current. Since at the commencement of break there is no power, and at the finish of the break there is no power, the question is: what is the power that is being broken in the actual switch? During the opening of the switch a spark is drawn out, and due to its resistance the current falls whilst the pressure across the switch contacts rises. The maximum number of kilovolt-amperes at the switch contacts would in consequence be of the order of half the current multiplied by half the voltage, or one-fourth of the short-circuit kilovolt-amperes of the generator at the time the break is taking place. If resistance or additional reactance were present in the circuit, the instantaneous short-circuit kilovolt-amperes would be less than 10 times normal, but whatever its value, the kilovolt-amperes broken at the actual switch contacts would be about one-fourth of that amount. I hope the author will give us his opinion on this matter, because it seems to me that this point is well worth attention by station engineers having increased demands for power but cramped for switchgear room, or saddled with doubtful or old-fashioned switchgear, in view of the large difference in price and size of switches of, say, 10,000 k.v.a. as against 40,000 k.v.a. breaking capacity. One other point in connection with the rupturing capacity of oil switches occurs to me. The author has explained that the designer's data are still largely empirical. Now is it too much to expect from the users of medium and large oil switches that on the occasion of a short-circuit they might note the particulars needed to arrive at the approximate value of the short-circuit? For instance, running plant in use at the time, distance of fault, particulars of cable,

reactances of generators, particulars of any other reactances affecting the short-circuit, nature of the short-circuit, voltage, periodicity, etc. If this information, together with details of the type of switch, were sent to the manufacturer he could fill in other details such as length of break, head of oil, etc., and the whole of such records over, say, a year or so, published by the Institution (with the consent of users and manufacturers) would prove of the utmost benefit.

Mr. W. De M. Landon: We are all agreed that high-tension and long-distance transmission schemes will of necessity use alternating current; but we have to consider existing conditions where direct-current plant is installed. The greater proportion of engineering works in Sheffield, for example, use direct current supplied from their own plants. In cases of that kind and where wide speed range is necessary, and where even cascade motors would not fill requirements, with large power schemes, we shall have to study some form of conversion by motor-generators. In connection with that, the author later on mentions power factor, in connection with distribution schemes. We know that low power factor is the case in a good many of the industrial applications. By using a motor-generator with a synchronous leading-current machine we can increase the power factor, drive a direct-current generator, and supply (to a certain extent, in any case) the lighting load, and also a certain proportion of the power load. This, as pointed out earlier, is necessary where a wide speed range is required. As to wide speed range, I know of one case in Sheffield—Messrs. Jessop's works—where there is an overall variation of 7 to 1. With the direct-current motor one can get a very wide range if a low normal running speed is chosen. I may be an idealist, but I should like to ask whether it is not time, in large cities, to construct subterranean passages where feeders can be inspected from time to time, and where an inspector could travel equally as freely as if on the street surface. On page 271 the author mentions that switchgear on consumers' premises may be subjected to forces comparable with those now met with in large generating stations, and that means must be found to limit the power at a given point when a fault occurs. Those are points that will have to be very carefully considered, and a lead on such matters should be given to the electrical profession by a body such as the Institution. I agree with Dr. Cramp on the question of reactances. I think it means really that if they are correctly designed—and the same applies to oil switches—we find that many of the limitations raised in the paper are cut out altogether. On page 270 the author brings out a point as to waste-heat plants and other local economical sources of power. We all know something of that. In one place within 20 miles of Manchester the local power station, which is one of consequence, would be totally outclassed by the power that could be obtained from waste gas and steam at a large steel works in the particular area. I can corroborate the author's statement regarding current transformers on page 292. I experienced one such case where similar transformers on the system were in every way satisfactory, and the destruction of the particular transformer was, at that time, somewhat inexplicable.

Mr. S. Ferguson: The paper is exceedingly useful to those engineers who are laying out new generating stations. Reactances are destined to play a very important part in the large schemes now contemplated. The factors which have led to their adoption are the need for maintaining the supply pressure under any fault conditions, the desirability of limiting the mechanical stresses due to short-circuits on the system, and the necessity of limiting the power to be interrupted by the oil switches installed. If we consider that the whole of the power in a central station is concentrated in the busbars, then, in order to maintain the pressure on those bars under fault conditions, it is necessary that there should be sufficient reactance in each circuit which is tapped on to them. Generally both generators and feeders will require additional reactance. Then there arises the question of a fault on the busbars themselves, which leads to the sectionalizing of the bars and the insertion of a reactance between each so as to limit the operation of such a fault. I think a combination of generator, feeder, and busbar reactances will be the ultimate scheme adopted in large stations. The first step, however, usually taken in existing medium-sized stations is to install busbar reactances. It may be of interest to show the effects of busbar reactances in the medium-sized station. Figs. E and F were prepared in connection with an existing 6,600-volt three-phase station in which it was proposed to divide the 60,000 kw. of plant into three sections of 20,000 kw. each and to insert reactances between each. Fig. E indicates the maximum initial energy output in kilowatts and Fig. F the maximum initial current obtained with a single-phase short-circuit occurring at varying distances from the central station and with various values of busbar reactance. The average generator inherent reactance was taken at 6 per cent and the faulty feeder as 0·15 square inch duplicate. Curve A in each case represents the values obtained without any busbar reactance; Curve B the values with busbar reactances of $3\frac{1}{8}$ per cent with an interchange of 1,000 amperes or $6\frac{1}{4}$ per cent when rated on the full capacity of the section; curve C the values with reactances of $3\frac{1}{8}$ per cent with an interchange of 500 amperes or $12\frac{1}{2}$ per cent at section capacity (this was the one adopted); curve D the values with reactances of $6\frac{1}{4}$ per cent with an interchange of 500 amperes or 25 per cent at section capacity; and curve E the values with reactances of $12\frac{1}{2}$ per cent with an interchange of 500 amperes or 50 per cent at section capacity. The curves do not take account of the power which may be fed into the system by synchronous machinery, or the effects of the normal load at the time the fault occurs, but they show comparative results with the varying factors. It will be seen that the adoption of $12\frac{1}{2}$ per cent reactance reduced the initial energy output and the initial short-circuit current to about one-half, thus reducing the mechanical stresses to one-quarter. This result is accomplished with reactances having an energy loss of about 3 kw. for each single-phase unit. The cost is only 3 to 4 per cent of the capital value of the plant, and the space occupied for each coil about

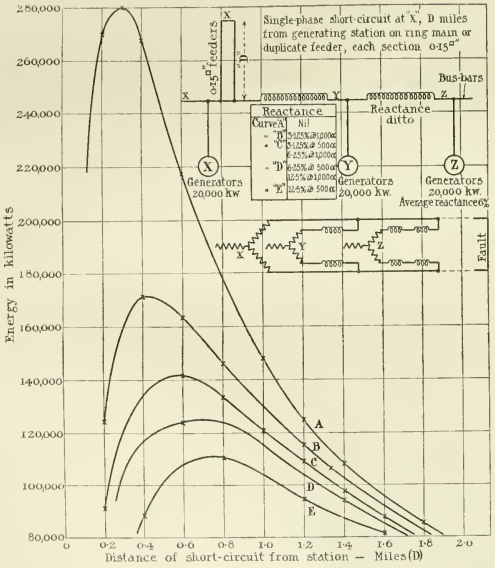

Energy in kilowatts
280,000
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
0
0·2
0·4
0·6
0·8
1·0
1·2
1·4
1·6
1·8
2·0
Distance of short-circuit from station — Miles (D)
Single-phase short-circuit at X, D miles from generating station on ring main or duplicate feeder, each section 0·15Ω
0·15Ω feeders
Bus-bars
Reactance
Curve A Nil
" B 5·25% @ 1,000 amps.
" C 5·25% @ 500 amps.
" D 6·25% @ 500 amps.
" E 12·5% @ 500 amps.
Reactance ditto
Generators 20,000 kw.
Generators 20,000 kw.
Generators 20,000 kw. Average reactance 6%
Fault
A
B
C
D
E

Fig. E.

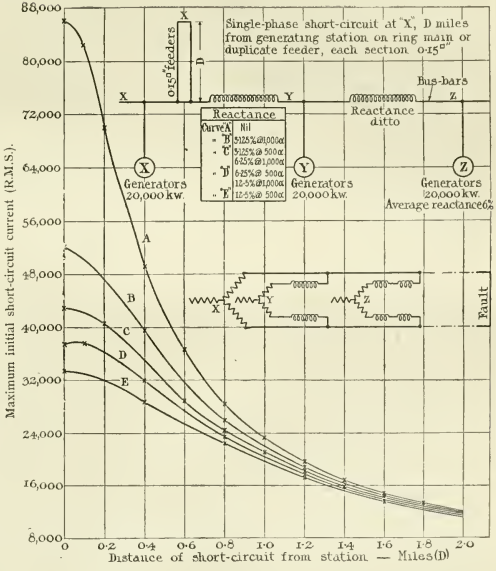

Maximum initial short-circuit current (R.M.S.).
88,000
80,000
72,000
64,000
56,000
48,000
40,000
32,000
24,000
16,000
8,000
0
0·2
0·4
0·6
0·8
1·0
1·2
1·4
1·6
1·8
2·0
Distance of short-circuit from station — Miles (D)
Single-phase short-circuit at X, D miles from generating station on ring main or duplicate feeder, each section 0·15Ω
0·15Ω feeders
Bus-bars
Reactance
Curve A Nil
" B 5·25% @ 1,000 amps.
" C 5·25% @ 500 amps.
" D 6·25% @ 500 amps.
" E 12·5% @ 500 amps.
Reactance ditto
Generators 20,000 kw.
Generators 20,000 kw.
Generators 20,000 kw. Average reactance 6%
Fault
A
B
C
D
E

Fig. F.

5 ft. diameter and 4 ft. high. It is evident that a very big insurance of the plant is effected at comparatively small cost. There is one point in connection with these curves which I want to bring out. With a fault in the generating station the value of the initial short-circuit current is determined mainly by the reactance of the plant, whereas with faults some little distance from the generating station the initial short-circuit current is determined by the impedance of the circuit made up of the plant reactance and the cable resistance. There is a certain length of feeder in connection with each size of cable where the cable resistance is the predominating factor and the plant reactance has little influence on the impedance. This is seen clearly in Fig. F, as the curves with different reactances in the generating plant merge into one another with faults about two miles from the generating station with 0·15 square inch duplicate feeder. The length of cable necessary, in order that the plant reactance will have little influence on the initial short-circuit current, varies with the size of conductor and the number in parallel. There is, however, with every conductor a definite length beyond which the plant reactance has very little influence. This may be of interest to those engineers who are increasing the capacity of their generating plant and wish to know how this will affect the possible short-circuit currents which may be obtained in their substations. One point, however, should not be overlooked in connection with this matter, namely, that the heavier capacity of plant would be better able to maintain the pressure under short-circuit conditions than the smaller capacity of plant, and in this respect a greater duty would be thrown upon the oil switch. I agree with the author when he says that importance should be given to the correct proportioning of the impedance of the different parts of the system. Recently I came across a 5,000-kw. alternator which had been designed with an inherent reactance of $2\frac{1}{2}$ per cent. It is evident that exterior reactance in this case is highly desirable, as the initial short-circuit current would be as bad on this machine as on a 20,000-kw. machine with 10 per cent inherent reactance. I think that all engineers should get to know what is the average inherent reactance of their plant and forward this information to their switchgear suppliers so that they may estimate what initial short-circuit current may be expected at any particular point in the system. The author states that generally the machine and transformer bank will form one unit, all switching being carried out on the high-voltage side. There is no doubt that to put the reactance in the transformer itself is a very nice arrangement, but it has one important disadvantage, it requires high-tension switching in the main generating station The American tendency seems to be to treat the transformer and line as one unit and to do all the automatic switching on the low-tension side so as to avoid the high-frequency surges that are set up with high-tension switching, which are generally accepted to be the most disastrous to power transformers, etc. I have recently seen two very bad examples of what has happened with high-tension switching on 6,600-volt systems. In one case a 1,000-kw. motor-generator was burnt out when switching it into circuit, due presumably to the surge set up. In another case, when certain substation power transformers were being switched on from the main generating station the surges were sufficient to break down the current-transformer primary between turns, and also flash over to earth, a distance of nearly $3\frac{1}{2}$ inches. If we have these effects with switching on 6,600-volt systems, what are we going to have with 30,000-volt switching and with the very much increased capacity of plant that is now contemplated? I am of the opinion that the above breakdowns would probably have been avoided if charging resistances had been supplied so as to reduce the initial pressure applied to the windings. The equipment, however, in both cases was many years old and installed before charging resistances were commonly used. It is rather significant that although the plant had been in commission for a number of years the breakdowns should only occur recently, and this leads to the conclusion (which is borne out in other directions) that the surges set up with high-tension switching gradually cause deterioration of the insulation of the windings until a point is reached when breakdowns occur. I think that in switching a transformer in and out of circuit it is desirable wherever possible to energize it and de-energize it on the low-tension side. The author has given some figures dealing with the maximum possible power which can be got through a 0·1 square inch feeder one mile long, on a 6,000-volt system. I estimate that a single-phase short-circuit would give about 42,000 kw. and a three-phase short-circuit about 84,000 kw. It is useful to keep these figures in mind, for they enable one roughly to estimate the amount of power that may be got through any particular length of feeder of any section. The power will vary directly with the section of conductor and inversely with the length of feeder; it also varies as the square of the voltage, so that we may have 25 times the energy output through a definite section and length of conductor on a 30,000-volt system that we have with a 6,000-volt system. It is evident from these considerations that the arrangement put forward by the author in Fig. 3 has considerable advantages in limiting the power on a fault in the substation by the ohmic resistance of the conductors. The arrangement also has the advantage that a short-circuit current limited by the feeder resistance has a high power factor, which is helpful to the oil switch in interrupting the fault. With regard to the rupturing capacities of oil switches, I think purchasing engineers should request a certain minimum amount of information in order to make a comparison of the switches offered. I agree with the previous speakers that there is a great deal of uncertainty about the breaking capacity of any particular switch, and the best way to make a selection is by a comparison of the various qualities which go to make up a good switch. The factors which I think should be taken into consideration are:—Head of oil above breaking point; length of break per phase; number of breaks per phase; speed of break at the point where contacts separate; distance between live metal and earth in air and in oil; method in which the phases are separated; shape and strength of oil

tanks and fastenings; shape of contacts; size of air cushion at top of oil; style of vents for the liberation of the gases; and whether auxiliary devices are provided to open the circuit in two steps as by the insertion of reactances momentarily. Although all these factors influence the breaking capacity of a switch, it is a difficult matter to assess the relative value of each. For heavy powers the multiple breaks per phase have a number of advantages. The energy is split up at a number of points and there is an increased likelihood of the switch finally rupturing the circuit when the current is at zero value. For 30,000-volt systems four breaks in series per phase make a good arrangement. I think that spring loading of oil switches is desirable, and tests prove that there is less likelihood of the switch sticking when it should operate automatically. Separate tanks for each phase are also desirable for heavy powers, in that the worst fault that could happen is a breakdown to earth, which is usually limited by neutral-point resistance. Elliptical tanks are also desirable, as they will yield under the pressure generated in the tank and return to their former shape. Many rectangular tanks have been bulged and rendered useless after heavy powers have been broken in them. The method of liberating the gases generated in a switch designed for heavy powers is important, and it is desirable to have pipes through which any discharge could pass which is clear of all live gear. I hope that ere long we shall have British rules for oil switches which will guide purchasing engineers in their selection for any particular duty. German rules have existed for a number of years, but I am afraid they are out of date, in that they ignore some very important factors. With regard to the style of reactance shown in Fig. 26, I think it is open to criticism on one or two points. In the first place a reactance should protect a generator or other apparatus from high-frequency surges; this, however, is only accomplished by the concentration of the pressure across the reactance windings. I am afraid that with bare conductors such as are shown, and with only a small clearance between them, there will be a possibility of breakdown between turns, particularly when it is remembered that the reactance is liable to attract dust. In the second place I am not convinced that the concrete blocks will be entirely satisfactory to withstand the pressures which may be impressed across them. If there is a short-circuit immediately behind these reactances we get the full line pressure across them, and if the concrete blocks have absorbed moisture or become dirty it is questionable whether they will stand up to this pressure. I think the porcelain-clad reactance illustrated by Mr. E. P. Hollis in his paper on "Reactance and Reactance Coils in Power Circuits" (*Journal I.E.E.*, 1914, vol. 52, p. 254) has many advantages if the conductors are insulated. It will be seen from the illustration shown in the above paper that the cables are carried in porcelain racks which would give ample insulation even if the insulation on the conductor were not present. These porcelain racks are keyed into the concrete core which is supported on a concrete base, and are also keyed to an outer wall of substantial porcelain insulators. The insulators and concrete blocks are cemented together so as to make a good mechanical job and capable of standing the mechanical strains put upon them. The reactances are supported on porcelain insulators which increase the insulation to earth and provide a passage for the air to pass through the ducts arranged longitudinally through the reactance. This type of reactance has been used very extensively in America and with very satisfactory results. For reactances placed in busbar circuits I think that no money should be spared in making the apparatus of the highest possible insulation in view of the serious trouble which might result from a breakdown at this critical part of the system.

Mr. J. L. Thompson: With regard to the first part of this paper I have very little, if any, criticism to make, but before passing on to the points I wish to discuss, I should like to endorse the author's general remarks for the adequate protection of supply systems and especially those whose growth has been rapid yet piecemeal. These systems that have been built up bit by bit are in general those in which continuity of supply is a vital necessity, and hence if the old and early equipment is to be relied upon it must have every possible protection from strains and stresses set up by heavy fault currents. By the insertion of current-limiting reactances of suitable design and value in suitable positions, the stresses set up by fault currents can be limited to values that can be safely withstood by the existing machines and apparatus. With regard to the design of current-limiting reactances, the author deals with this point in Appendix VI. To me this appendix is very incomplete since it only briefly deals with the subject. Further, he only describes one particular build of reactance coil while there are many types on the market, all of which are doing heavy and satisfactory duty. There are two main classes of reactance coil, those known as the air-core type and those of the iron-clad type. Both these types are in extensive use, and both can be designed and built to meet all conditions of service. Possibly the author has had very little, if any, experience of the iron-clad type or he would not have made such a sweeping statement as that "there is no gain in the use of iron in the design." The vital function of a reactance coil is that the voltage choked must be proportional to the current flowing through the windings up to the maximum possible current that can flow. If this requirement is met then it matters very little how the coil is manufactured and what material is used. This straight line characteristic up to maximum possible fault current is attained in the ironclad type. The chief claim made for the air-core reactance is that it has a straight line characteristic; while this is true it has possible disadvantages. It must be constructed on the open or dry type principle; this brings with it the following disadvantages. It has a heavy stray alternating field which necessitates it being isolated from all machinery and girder work or it may lose its straight line characteristic and cause heating trouble. It requires large floor-space and long cable runs. It has not a very heavy overload capacity, and further it must be guarded against contact. In comparison the ironclad type has no stray field and hence can be oil insulated and mounted

in a tank and can be placed in any position that a transformer could occupy. Also it can be placed adjacent or underneath the generators, thus reducing cable runs to a minimum. Further, much less floor-space is required, and also it is a safe and open piece of apparatus since the tank can be earthed. This type has also a very heavy overload capacity, being capable of 300 per cent of full load for half an hour without damage. The author says, and rightly, that these reactance coils are generally required for important circuits and must not lower the safety factor of the system. This point is taken care of in the iron-clad type, for every turn is insulated to withstand full line pressure, and also the windings are heavily insulated from the core. If further safety is thought necessary it can be obtained; in fact this type can have a three-fold safety factor; for the windings are insulated from the core, the core can be insulated from the tank, and if thought necessary the tank can be mounted on insulators in a similar way to the air-core type. I only know of one case of a two-fold safety factor, and that is in connection with 12 busbar reactances to be installed in a station of over 100,000 k.v.a. capacity. In this instance the core is to be insulated from the tank and the tank earthed. In Fig. 5 the author shows step-up transformers having 4 per cent reactance. These step-up transformers are necessary for attaining the required busbar voltage, but by having 4 per cent reactance they preclude the use of reactance coils. Here we have an iron-clad reactance, and if transformers can be manufactured to stand severe strains and exert their function as a reactance coil then iron can with safety be used in the manufacture of reactance coils. Iron-clad reactances are divided into three classes: busbar, generator, and feeder. I have designed reactances of all these types which are giving satisfactory service. From the point of view of cost, a word or two might be useful. For busbar work the iron-clad is the cheaper proposition as regards cost of coils, floor-space, and cable runs. For generator work the cost of coils become more nearly equal, but the advantage of floor-space and economy in cable rests with the iron-clad type. For feeder work the air-core type is cheaper, but this advantage must be weighed against floor-space and the safety of the employee who may have to be near or in close proximity to the apparatus. All types of iron-clad reactances have heavy overload capacity, are fool-proof, and there is less fire risk and the losses are lower.

Mr. H. A. Ratcliff: The author certainly makes out a very strong case for the use of reactances, but nevertheless I think it is a mistake to regard them as the panacea for all the troubles incidental to the operation of a high-tension electricity-supply system. They certainly serve as valuable safeguards under certain conditions, and the extent to which they should be used is well summed up by the author in the italicized paragraph in the middle of the first column on page 274. With regard to location, I think a certain amount of external reactance in the generator circuits is beneficial; when the generators are connected to the busbars through transformers, external reactance may not be quite so necessary, but even then a little is desirable in some cases. Certainly when the generators are coupled directly to the busbars instead of through transformers external reactances possess the advantage that they afford some measure of protection in the event of short-circuits occurring in the machines, and further, as Mr. Juhlin has pointed out, they protect the generator end-windings from the effects of the steep wave-fronts which exist under abnormal surge conditions. For the same total amount of reactance in the circuit, and therefore the same current-limiting conditions, the possible mechanical strain on the generator windings will obviously be less when some of the reactance is external. The most suitable location for these reactances is probably between the busbar sections, and no doubt ultimately that is where they will mainly be used. I do not consider that they are any advantage in the feeders, and in fact they may be a positive disadvantage. When installed in the machine circuits it is of course simply a matter of regulation and nothing else, and when connected between the busbar sections it is usually possible to arrange the running of the plant so as to avoid under normal conditions any of the objectionable effects incidental to their use; but if they are connected in the feeders it seems to me that it would be a very difficult matter indeed to obtain a reasonably uniform degree of regulation on all the feeders. Moreover, I question whether such a form of protection is necessary in feeders, and I am inclined to think that the money spent on feeder reactances would be employed to better advantage in putting the very best possible work and materials into the cable joints and the switches at the far ends of the lines. I doubt whether modern high-tension feeders, if well made and well laid, ever break down internally, that is to say, I do not think that any faults develop internally; but in the event of such a fault occurring it is reasonably safe to assume that a short-circuit between phases would develop simultaneously with an earth, owing to the intense local heating referred to by the author. Externally originated earth faults occur mainly at the joints or at places where the cable has been mechanically damaged, and they are invariably cleared perfectly satisfactorily by protective gear of the core-balancing type. Switches of the type usually employed at the distant ends of the lines are probably responsible for as much trouble as cable faults, and the cause is quite as often of a mechanical as of an electrical nature. Flimsy, variable contacts and unreliable trip actions are undoubtedly the cause of many switch failures, although it must be admitted that in many cases the latter defect is frequently the salvation of the switch. In connection with sectionalizing the busbars the author mentions that obviously the system would have to be sectionalized as well, but he does not emphasize the point. Actually the matter is one of considerable importance because when the busbar reactances are transmitting any appreciable load there must be a difference in the conditions on the several busbar sections. There will be a difference in voltage if the power factor is low, and if the power factor is high there will be a phase displacement; therefore any linking up of the sections externally to the generating station would give rise to circulating

currents in the feeders, and also largely neutralize the protective action of the reactances. The voltage difference between sections is greater the lower the power factor. That emphasizes the importance of maintaining a good power factor on the system. The author suggests that when transferring energy from one section to another at a low power factor the whole of the magnetizing current could be supplied by the section which is being fed. That avoids the high voltage drop in the reactances, but rather complicates matters for the engineers in charge of the station, and I should also rather question whether it would always be good for the generators concerned. On an ordinary industrial power-supply system where there is not a preponderance of synchronous machinery the average power factor probably does not greatly exceed 70 per cent. That is a very low figure and means that the magnetizing current is equal to the load current; it is therefore quite a serious matter. Undoubtedly the first step towards making really effective use of reactances is to raise the power factor of the system as a whole. With regard to the method of sectionalizing the busbars, the author refers to two systems, the "tie busbar" or "star" system and the "ring" system. The former is comparatively a recent innovation. In his summing up on the respective merits of the two systems the author is not very decided either way, but he appears to prefer the "star" arrangement. It certainly has many advantages, but it may also have one or two disadvantages. First of all it involves the necessity of another set of busbars, which will have to be fairly heavy and which may of course break down. I do not think they would, but there is always that possibility to be taken into consideration. In the event of the tie busbars breaking down there will be a fairly heavy current fed into them from all the sections in parallel. Also in the event of a fault on one section there is a very heavy responsibility upon the reactances connected to that section, the greater the number of sections the greater being the responsibility, until ultimately nearly the whole of the busbar voltage is absorbed across one set of reactances. With the ring system the responsibility is divided between two sets in the case of a fault on any one section, with a lesser degree of responsibility on the successive sets of coils. I have had occasion to make calculations in connection with the employment of reactances and am therefore able to appreciate the amount of work involved in the production of the numerous curves, which undoubtedly constitute a valuable feature of the paper. They should prove very useful because the alternative calculations are rather tedious. The formula on page 283 appears to be unnecessarily complicated and I should therefore like to know the author's reason for retaining it in that form. When making similar calculations I derived the formula $f=(A+B)\div(A+N\,B)$, which may also be expressed in the form

$$f=\frac{B/A+1}{N\,B/A+1}.$$

This is in agreement with the curves given in the paper, and in fact, the author's formula reduces to the same simple expression. In the case of the ring system the calculations are rather involved when there are more than five sections, and probably that is one of the reasons for preferring the star arrangement of connections. With the star or tie busbar system the total current in the event of a short-circuit on the tie busbars is equal to $C(100\,N)\div(A+B)$, where C equals the normal full-load current of one section. All the above figures refer to R.M.S. values; the asymmetrical maximums may of course be considerably higher. On a three-phase system with star-connected sections in the event of a short-circuit on one section the voltage across the reactances connected to it will depend upon the number of sections and will be equal to

$$v\times\frac{B\,(N-1)}{A+B\,N}\quad\text{or}\quad v\times\frac{(N-1)\,B/A}{1+N\,B/A},$$

where v represents the pressure per phase. It may therefore under certain conditions attain a fairly high value and, as previously mentioned, constitutes one of the disadvantages of the tie busbar system. A previous speaker has criticized the use of the word "reactance," but I have nevertheless used it in the same sense as the author, although in many cases "inductance" would be the correct term. There is, however, some justification for the former usage because for convenience of calculation, etc., the coils are rated in terms of the percentage reactive voltage induced between their terminals when passing normal full-load current. I was rather interested in the point mentioned on page 289. It is a very interesting feature of these concrete-supported coils that should high-frequency surges occur in the circuit the concrete acts as a high-resistance non-inductive shunt. It is the sort of thing that might have been expected to some extent, and I should like to know whether the reference to it is more or less anticipation or whether it has actually been known to occur. My experience of pyro-electric conductors is that a very small current sustained for a very short time produces intense heating, frequently with disruptive effects. I do not know whether it is possible for that to occur in a case like this, but it does seem possible that owing to the high negative temperature coefficient of the pyro-electric conductor the resistance might be lowered to a sufficient extent to allow the main voltage to break down the concrete between the turns of the coil under conditions where there is nearly the full phase voltage across the reactance. This may appear to be meeting trouble half way, but further information on the point would certainly be of interest. I am in agreement with the author as regards the ironless form of construction. These additional reactances are used for the purpose of protecting machines and apparatus already possessing more or less internal reactance which is dependent at least partially on iron-cored magnetic circuits, and therefore it is an advantage to have the additional reactance in a form quite independent of any magnetic characteristic of the circuit. The author refers to mechanical stresses but does not mention anything about the bracing of the coils. When they first came into vogue some seven or eight years ago the Americans emphasized the importance of bracing them together

owing to the enormous mutual stresses set up. Usually there will be attraction between the coils, but apparently not of sufficient extent to justify this bracing. The coil illustrated in the paper is mounted on what would appear to be rather weak insulators, certainly not capable of standing very severe lateral strains, and it would therefore be interesting to have the author's opinion as to whether any form of cross-bracing is really necessary. I am very glad to see the reference to current transformers. The design and construction of some current transformers is distinctly bad and they are undoubtedly in many cases the weakest link in a supply system. They are subjected to enormous strains, both electrical and mechanical. I agree with the author that they should be made with the largest possible section of conductor consistent with reliability and accuracy in the duties they have to perform. Certainly it is advisable to have them rather too large than too small. I have seen transformers wound for a density of no less than 3,000 amperes per square inch. That is a sufficient handicap under normal conditions and leaves no margin for dealing safely with abnormal current rushes.

Mr. A. G. Ellis: The size of unit now under consideration—20,000 to 30,000 kw.—has led to a good deal of development and we are in a position to build generators and transformers to deal with these capacities. But there is the question of intermediate switchgear between the generators and the step-up transformers. Such gear is, I believe, generally considered too cumbersome a proposition because it has to deal with 2,000 or 3,000 amperes at 5,000 or 6,000 volts, which is fixed by the necessity of a rigid stable winding in the turbo-generator stator. I should like to hear further remarks by the author on this point and as to whether it is usual practice to put any isolating switches or isolating links between the generator and the step-up transformers. Regarding the protection of such large units against deleterious effects of short-circuits, the whole question amounts to one of reactance. In such modern large stations the reactance of the whole plant is generally such that the steady short-circuit current would be from twice to three times normal. As has been pointed out, it is really the instantaneous short-circuit that we have to guard against, and if this cannot be dealt with by the inherent reactance of the whole system—that is generators plus transformers, plus all other apparatus in circuit—it is necessary to put in an additional reactance. From the point of view of the transformers, external reactance is really preferable, as it results in lower stresses in the transformer under short-circuit. But it is possible, and in fact it is the usual practice nowadays, to build transformers with such an amount of internal reactance that they will still cope with mechanical stresses set up by the current on short-circuit. The internal reactance of modern large power transformers is as high as 5, 6, or 7 per cent. This, with the inherent reactance of the generators, is usually sufficient to obviate the necessity for external reactances. These latter are more usually required in cases of extension of existing generating stations to cope with the increasing demands. It is just this which influences, to a large extent, the type of reactance chosen. It is a pity the author did not take a more general survey of the present practice as regards these protective reactances, as the lay mind is left rather in the dark as to the relative merits of the air-core and iron-clad types. Reference has been made to the iron-clad type mentioned in Messrs. Peck and Faye-Hansen's paper. This paper introduced a new type of iron-clad reactance, which was, in effect, a shell-type transformer with the tongue or middle core removed so as to form a large air-gap, required to give the necessary choking effect. The air-core concrete-frame type described in the paper is the American type. On the Continent both air-core and iron-clad types have been extensively used according to the requirements of the individual cases. I have designed for Continental firms a number of reactances of both types, but still differing in construction. The iron-clad reactances were designed from standard core-type transformers with a number of short air-gaps in series introduced into the limbs. Reactances of this type built by a Continental firm are at present in operation in this country. The author's statement that "there is no gain in the use of iron" in such reactances certainly needs qualification. One of the chief gains in the ironclad type is that the magnetic field is confined to the core and there is no stray field as in the air-core type. This stray field becomes a nuisance if the reactance is placed in the proximity of iron-girder work or electromagnetic instruments. It is just in cases where the space available is cramped, as is often the case in extensions, that this consideration is of importance. Another point I should like to mention is that the general tendency in this country as regards transformers is to prefer the oil-immersed type. I believe this is generally accepted. On the Continent, however, for small or moderate-sized units the dry type is preferred, but in this country this type of transformer has made little headway. The question of reactance coils is quite similar. The apparatus is in itself practically a transformer with one winding. Another point is the bracing of the coils. It is generally recognized that the shell-type transformer construction, as described for reactances in Messrs. Peck and Faye-Hansen's paper, forms a very robust construction, the windings being completely iron-clad. Regarding comparative cost of the two types, this depends largely on the number of times normal current up to which the reactance must give a straight-line volt-ampere characteristic. Where the current limitation is not too high, say up to ten times normal, the iron-clad type can be run normally at a higher induction density and can compete in cost with the air-core type. There are certain cases of large reactances where forced air-blast cooling must be adopted for the air-core type. The ventilating fan and motor add another link in the chain of auxiliaries, which reduces the safety factor of operation. This point should not be overlooked. Dr. Cramp referred to the question of core losses in these iron-clad reactances. These are of no importance since, in order to get a straight-line characteristic up to the maximum current (which may be 10 or even 20 times the normal current), the magnetization of the core at normal current and normal choke is so low that the core loss is negligible.

Mr. H. Pearce: Several speakers as well as the author have referred to the importance of sectionalizing the distribution system. I should like to include a small diagram (Fig. G) to emphasize this point and to lead up to some important conclusions. A, B, C, and D represent distributing centres or substations fed radially from a power house having four busbar sections. Each section may have one or more generators, but for simplicity in the diagram only one machine is shown for each section. The four substations are suitably coupled together by means of interconnectors and in the present diagram they form a complete ring main, though the exact arrangement would vary according to local circumstances. Oil switches are indicated in the customary manner, thus "X." It is of course to be understood that a single line on the diagram may represent two or more cables in parallel where the load conditions warrant it. Moreover, the hospital busbar is purposely omitted. In laying out or extending a large system of this type, it is now customary to install reactances between the different busbar sections. One such reactance is shown between sections 2 and 3. If

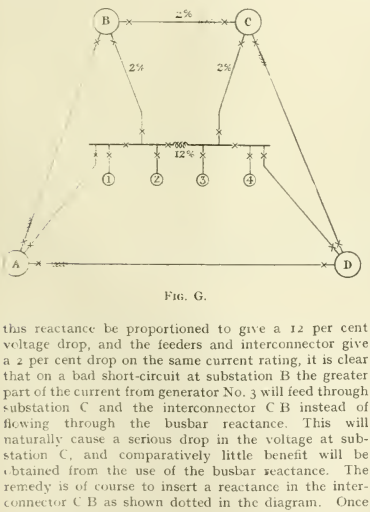


FIG. G.

this reactance be proportioned to give a 12 per cent voltage drop, and the feeders and interconnector give a 2 per cent drop on the same current rating, it is clear that on a bad short-circuit at substation B the greater part of the current from generator No. 3 will feed through substation C and the interconnector C B instead of flowing through the busbar reactance. This will naturally cause a serious drop in the voltage at substation C, and comparatively little benefit will be obtained from the use of the busbar reactance. The remedy is of course to insert a reactance in the interconnector C B as shown dotted in the diagram. Once having admitted the necessity for reactances in interconnectors the next step is to omit entirely the busbar reactances in the power house, open all the busbar sectionalizing switches, and run each section as a separate system—except that these systems are interconnected through the substations. From this arrangement the following advantages are obtained:—(*a*) A power-house busbar fault cannot cause as great a shock to the system as would occur with the usual lay-out. (*b*) The substation oil switches need have no larger breaking capacity than usual. (*c*) The power-house oil switches have no heavier duty to perform than the substation switches. (*d*) When extending a system where the breaking capacity of the power-house oil switches has already been reached, efficient sectionalizing will prevent undue strain on the oil switches. (*e*) The reactances only carry the floating load that passes between two adjacent sections. (*f*) Busbar section switches can be installed to couple adjacent sections. (This should only be permitted at times of light load, and it should be strictly forbidden to couple together more than the agreed number of machines. Thus in the diagram where only one machine is shown on each section, two machines must never be coupled together.) (*g*) Where the conditions warrant it, the interconnector reactances can also be short-circuited at times of light load. Synchronizing would have to be carried out in the substations before switching in an interconnector. Suppose that the attendant in substation B finds his section isolated from the rest of the system; before switching in the interconnector B A he must see that the two systems are in synchronism. He has no control over the speed or voltage, but all that is necessary is for the power-station attendant to perform the ordinary operation of synchronizing between machines No. 1 and No. 2, with the single exception that he must close no switch. He would get the synchronizing needle gradually creeping round and it would be left to the substation attendant to close the interconnector switch at the right moment. There is one feature that at first sight appears rather disquieting—I mean the necessity for feeding the synchronizing magnetizing current from one generator to another through the interconnectors. But the author refers to the fact that some existing interconnectors between adjacent systems have considerable reactance in circuit, so that no serious difficulty should be incurred. I think that this principle of sectionalizing will take a much more prominent place in the future than it has ever done in the past, and I believe that it will prove the means by which the new super-station of the future is enabled to feed the existing distributing centres without involving mammoth oil switches and without incurring the unavoidable risks that must always occur with the concentration of such immense power as is contemplated.

Mr. W. A. Coates (*communicated*): The author's implied comments on the reliability of relays in section XII of his paper are somewhat reminiscent of the report by the Committee of the American Institute some 14 years ago when this Committee recommended that only overload relays should be employed, other types being considered to be in the experimental stage. Selective action has been obtainable by means of fixed time-limit relays for some years past, but such instruments are essentially short of the ideal inasmuch as they do not take any account of the intensity of the short-circuit currents. As is well known the ordinary inverse time-limit relay has a curve of operation such that on large overloads the instrument acts practically instantaneously, and thus selective action is impossible. Some four years ago a relay was patented in this country

combining the advantages of the inverse time-limit relay with that of the fixed time-limit relay (Coates & Ferranti, Ltd., No. 29,861, 1913). About the same time in America the Westinghouse Company produced an instrument having similar characteristics although the principle of operation was entirely different. This instrument is of the induction motor pattern and is fitted with a very small compensating transformer, which is so designed and connected as to set up an opposing field to that caused by the current in the series coil. In this manner the speed of the instrument is limited on the higher overloads and it is possible to obtain operating curves of typical inverse time-limit form but which are entirely separate from each other throughout their length. This is illustrated in Fig. H. This method of controlling the speed of the relay disc by the builders. Experimental research since that time has shown the fallacy of such designs and on modern switches length of break is not so much a variable depending on the k.v.a capacity as one which changes with the normal voltage It is only within the last few years that the value has been properly appreciated of a large head of oil and also of an ample air space above the oil. The author is of course, perfectly correct in stating that increase in strength can be carried to an absurd and useless extent, but it is doubtful whether there is a switch on the British market to-day which is mechanically too strong when taking into consideration the other features of design such as those mentioned above. There is not the slightest doubt that British switchgear designers are proceeding on the correct lines in keeping mechanical strength always in sight Con-

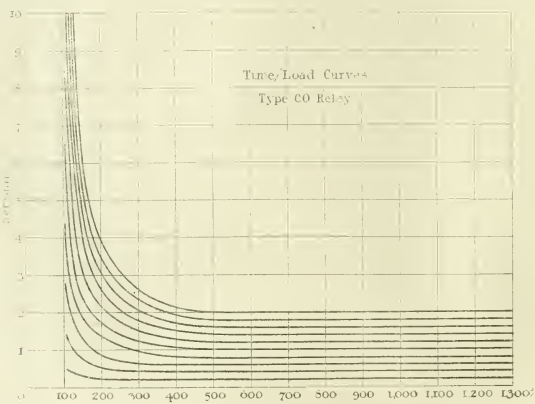


FIG. H.

is so delicate that time differences between the settings of one relay and those of another can be reduced to 0·04 second. In practice such small differences are never required, as it is necessary to allow a sufficient margin of time between adjacent relays to ensure that the contacts on the oil switch nearest to the fault have properly opened. On modern switches this time would be of the nature of 0·15 to 0·2 second. A similar device working in conjunction with a wattmeter relay movement with very fine settings is employed for use on duplicate feeders, ring mains, and similar systems, so that all ordinary systems of connection can be properly protected with these selective relays. Dealing with the rupturing capacity of oil switches, it may be of interest to note that some 8 or 9 years ago a comparison was made between the switches then built by two of the largest switchgear manufacturers in this country. It was found that the lengths of break used varied directly with the k.v.a. breaking capacity guaranteed

tinental-built oil switches are invariably much lighter than are those made either in America or in this country, although many modern Continental switches compare quite favourably with British-made switches in regard to length of break, head of oil, and size of air cushion. They fall short primarily in regard to mechanical strength of tank and speed of rupture. The result of this difference is that in many Continental switchgear installations spare switches are always kept in the power station in readiness to replace any switch which may explode or be seriously damaged in operation. It is by no means uncommon for such exchange to be necessary. In the course of a recent trip to the Continent I noticed a very distinct change in this respect, and the latest switches built by some of the Continental manufacturers are much stiffer in their mechanical construction, although no appreciable change has yet been made in operating mechanism so as to increase the speed of break.

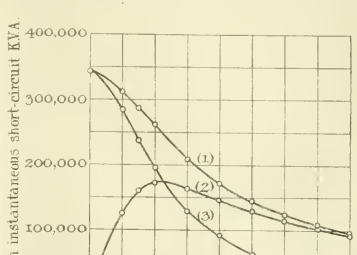
Mr. E. B. Wedmore *(in reply)*: Several references have been made to Fig. 1 and to the rupturing capacity of oil switches. The whole subject is under consideration by committees dealing with standardization, and I hope that their work will result in the issue of information giving more detail. Meanwhile, curves have been published in the *Proceedings* of the American Institute for February, 1918.*

The design of protective devices able to disconnect a partially short-circuited winding presents considerable difficulty. We have, however, a partial solution, due to Messrs. Whitcher and Clough, fortunately applicable to very heavy machines where these have two or more windings per phase in parallel. The balance of current between the parallel windings is upset if one winding becomes partially short-circuited, and we can utilize this to cause disconnection of the machine. One example is given in the *Journal*, in my paper on "Automatic Protective Switchgear for Alternating-Current Systems" (*Journal I.E.E.*, 1915, vol. 53, p. 165, Fig. 20).

In the protection of the end windings the novel feature lies in separating the windings in different phases by earthed metal-work and bringing this earthed metal-work into intimate contact with the insulation, so that the insulation when destroyed will, as in a cable, form at once a good conducting path to earth.

It is satisfactory to have from a man of practical experience like Mr. McKenzie so much confirmation of what I have recommended.

Dr. Cramp has referred to the instantaneous phenomena accompanying the use of different combinations of capacity, reactance, and resistance. A great deal of work has been done on the academical side, but this is only slowly being reduced to a form available for practical application. The conception of "surge impedance" has gone a long way towards this. The subject is much too large to deal with in a reply of this kind. I agree with Dr. Cramp as to the importance of the subject, and of considering it in dealing with the problems referred to in the paper, but until we have the complete treatment available we shall have to be content with the approximate solutions which we have and which have proved adequate in the main. Dr. Cramp objects to the name "reactance" as applied to a particular piece of apparatus. It will require action by the Engineering Standards Committee to establish another word in its place. The term "reactor" has been used and might prove acceptable. The voltage difference across the terminals of a sectionalizing reactance is the vectorial difference between the voltages on the busbars it connects. These voltages may be the same in magnitude and yet show a big vectorial difference. I have not suggested that modern switchgear is "absolutely" reliable. My term was "non-speculative." Hilliard's combinations of switches and impedances have been employed commercially with advantage. They do not afford a general solution of the problems of controlling heavy circuits. In the discussion on Messrs. Peck and Faye-Hansen's paper † some years ago I recommended figures which were the best with machines then available, and which, after correcting for the differences between star and ring system alone, will be found to agree very nearly with those now recommended with modern machines having higher reactance.



(1) Maximum KVA (R.M.S.). (2) Energy component. (3) Magnetizing component.

FIG. J.

Distance	Curve 1	Curve 2	Curve 3
Miles	k.v.a.	k.v.a.	k.v.a.
0	343,000	0	343,000
0·2	311,000	125,000	284,000
0·3	286,000	160,000	237,000
0·4	260,000	172,000	195,000
0·6	208,000	163,000	128,000
0·8	172,000	146,000	92,000
1·0	145,000	130,000	62,500
1·2	124,000	115,000	46,000
1·4	108,000	102,000	33,500
1·6	95,000	92,000	23,700

Mr. Ferguson's diagrams (Figs. E and F) bring out strongly the advantage of adding a little artificial reactance to a circuit and also show that each further addition becomes less and less useful. Fig. E is interesting, but must be interpreted with care. It suggests easier conditions for a short-circuit near the station than for one half a mile away, whereas we know that the reverse is the case. The curves in Fig. J herewith are based on Mr. Ferguson's diagrams, and correspond to his curves B. My curve (1) gives the maximum kilovolt-amperes, which is the product of the current in Mr. Ferguson's Fig. F with the delta voltage. Curve (2) is the energy component, and is Mr. Ferguson's curve B in Fig. E. Curve (3) is the wattless component derived from the other two. This is seen to decrease rapidly, showing improving conditions for the automatic switches as the distance increases.

* E. M. HEWLETT, J. M. MAHONEY, and G. A. BURNHAM: "Rating and Selection of Oil Circuit-Breakers," *Proceedings of the American Institute of Electrical Engineers*, 1918, vol. 37, p. 41.

† *Journal I.E.E.*, 1914, vol. 52, p. 526.

If step-up transformers are associated with individual feeders rather than individual machines, they must be employed at a lower load factor. With large amounts of power this involves serious losses, so that economy compels us to face the problems arising out of switching at the higher voltage. Fortunately, these are not new in kind, but it is a repetition of the case that things which were previously negligible can no longer be ignored. I do not agree that the tendency in America is towards low-tension switching. Where the bulk of the power generated is transmitted at the generated voltage and a portion only is to be transmitted at a higher voltage, the transformers cannot be associated with the machines. Switchgear must be provided on the generator side, and there may then be no occasion for switchgear on the higher voltage side. On plants where the bulk of the power is transmitted at the higher voltage, switches have been employed economically between the machines and transformers arranged with a transfer busbar so that any transformer bank can be used with any machine. A local supply can also be taken at the generated voltage from this same installation. Unless some such installation is provided I see no occasion for isolating links or switches between the machines and transformers. Oil switches are already in use in this country having the necessary rupturing capacity in sizes up to 4,000 amperes.

One is familiar with the long schedules of details of oil-switch design indicated by Mr. Ferguson, but it is a puzzle for the user to know how to interpret them. How is a user to attribute factors of merit to each of the items? Take one item alone, for instance, viz. the head of oil. Is he to figure the rupturing capacity as directly proportional, or proportional to say the square, or square root of the head, or to some more complex function? How is he to figure the relative value of the same head in designs differing in type? Some of us have data on such details, but I confess to having no formulæ for shape of contact or style of vent. There is need for further investigation by carefully contrived experimental tests, based on present knowledge and designed to extend that knowledge. Meanwhile, users must be guided by results which have been obtained, and in the interpreting of them by the experience of those who know.

The design of reactances has been dealt with in the discussions in London and Birmingham, but I would add that the design shown in Fig. 26 has long since passed the experimental stage. There is nothing in the moisture bogey, neither does dirt present difficulty if a suitable factor of safety is employed in the creeping surfaces and clearances. In saying that "there is no gain in the use of iron," I am not suggesting that there is nothing to put on the credit side of the balance sheet, but some of the items some speakers have endeavoured to put there will be queried by the auditors.

I do not follow Mr. Thompson in his argument that there is less fire risk in a design employing large quantities of inflammable material, including oil, than in one constructed throughout of incombustible material and housed in a fireproof chamber. I suggest that a busbar reactance should be designed like a busbar, and not on lines we are compelled to employ in designing machines and transformers. It is not easy to demonstrate that high-frequency disturbances have been absorbed by a reactance with concrete frame in any particular case, but calculation shows that the leakage paths afforded by the concrete are likely to be helpful in dealing with temporary high-frequency phenomena. There is no danger from pyro-electric effects with the proportions employed. The forces met with in the use of these reactances are readily calculated and dealt with by the designers. External bracing is not necessary as a rule.

The system of distribution suggested by Mr. H. Pearce leads to serious increase of losses in the cables, and increase in capital cost, as when some machines are shut down some parts of the system have to obtain all their supply through long interconnectors.

Mr. Coates has not correctly interpreted my remarks in section XII. Clearly if one employs relays and switches in such a way that the whole supply may be affected by the failure of any one of these, this introduces new conditions. One cannot make switchgear so much better than all other kinds of apparatus as to guarantee absolute reliability. The only course therefore is to provide a stand-by. I do not quite follow Mr. Coates's remarks on oil-switch designs. With a switch of the commonest type, of which Fig. 30 is an example, and of a particular design, the rupturing capacity is nearly proportional to the linear dimensions over a certain range. It follows then that the rupturing capacity will be nearly proportional to any one of the dimensions if the same relative proportions are retained throughout, even though in varying any one dimension the rupturing capacity may not vary proportionally. At any voltage the rupturing capacity increases with length of break according to a certain law. We can determine how much of the space can be economically employed in length of break, and if we retain this proportion throughout the series, the rupturing capacity will be roughly proportioned to the length of break. As a matter of fact, within wider limits than might be expected we can vary the relative dimensions of head of oil, length of break, and air buffer without modifying the rupturing capacity materially, and thus it is open to us to choose dimensions which are convenient for manufacture, and for obtaining other desirable features, such as speed of break, and in the arrangement of the parts. As soon, however, as those limits of proper proportion are exceeded the design quickly deteriorates. Many switches now in use show defective proportions. The commonest defect is absence of adequate space above the oil, and as I have said before, one could considerably increase the actual rupturing capacity by baling oil out of these switches; yet some of them were sold as articles superior on account of the large head of oil.

BIRMINGHAM LOCAL SECTION, 20 MARCH, 1918.

Mr. R. A. Chattock: I agree that the large supply systems now being developed make effective control much more difficult to obtain, and this difficulty will probably increase in the future. The paper is therefore especially valuable in view of the large schemes for development that are now being considered. The author favours the use of reactances to limit the current that has to be dealt with by individual switches. There is no doubt that the use of reactance is detrimental to the proper maintenance of the voltage throughout the system, and makes regulation of the pressure more difficult. It therefore seems desirable to consider whether the current cannot be limited in some other way. The extension of the areas of supply will also require higher pressures to be used for distribution, and voltages of 20,000 to 30,000 will probably be employed. If the switching is done at these pressures, the amount of current to be controlled will be far less than at pressures of 6,000 volts, and this should render the use of reactances in and beyond the busbars less necessary. I think it will probably be found that reactance can be confined to the alternators and to the transformers, which will be external to them but will constitute with them one generator unit. I agree that reactance is necessary here, partly for the protection of the machines themselves, and partly to prevent excessive rushes of current into faults on the system, but I deprecate the use of reactances in the busbars if at all possible. This latter suggestion is made to prevent large rushes of current from one section to another and so to reduce the interference with the voltage on those sections that are not directly connected with the fault, as well as to relieve the strain on the switches. I do not think a momentary interference with the voltage will matter so long as the switches can be relied upon to operate properly. The author refers to the use of selective protective apparatus and states that this throws a severe duty upon the switchgear. Surely this is not the case on an earthed system with a limiting resistance; nearly all faults are primarily earth faults which often develop into short-circuits between phases, and if the selective apparatus can cut out the faulty section while its fault current is limited, the strain on the switchgear will be easily met. Again the balanced-current protection as applied to split-conductor cables enables faults to be eliminated before the current values have got out of hand. The development of these methods would seem desirable before adopting the use of reactances in the distributing system. The author refers to the necessity of two spare generator units of the largest size in a station. I should like to point out that it is generally proposed to link up these large stations by substantial connections, and in this way one spare should be sufficient in each station, as it could serve perhaps several stations.

Mr. F. Forrest: It is now generally recognized that on any large alternating-current system the use of current-limiting reactances for the protection of the switchgear and generators is sound engineering, and their introduction is no longer regarded as a confession of failure on the part of designers to produce switchgear and machines capable of operating satisfactorily under the severest short-circuit conditions. The chief points at issue are where these reactances should be connected, and their rating. The paper deals with these points in a very complete manner. On any large system the majority of the short-circuits occur outside the generating stations, either on the cables or on apparatus connected to them. A reactance should therefore be connected in series with each feeder, or with groups of feeders at the generating stations, and these reactances should be so proportioned that each feeder switch can safely break the maximum short-circuit current that the reactance in series with it will pass. The switches of smaller capacity installed in substations or on consumers' premises would be protected by this reactance, plus the impedance of the cable to the generating station, so that the risk of their destruction on the occasion of a bad short-circuit would be very materially reduced. A 4 per cent reactance for feeders appears to be about the right amount, and does not interfere appreciably with the regulation of the supply voltage. Experience shows that generators and their cable connections should also be protected by reactances, and as the inherent reactance of the generator does not give adequate protection against a short-circuit in the cable connections, or in the end-turns of a generator when it is running in parallel with a number of others, separate external reactances should be adopted. Where the generator is connected to a step-up transformer, this external reactance should be connected between the step-up transformer and the busbars. The complications introduced by busbar section reactances are so serious that an overwhelmingly strong case must be made out for their adoption before inserting them. Bearing in mind that more than 50 per cent of the capital of any large bulk-supply undertaking is likely to be expended upon the transmission lines and distributing network, anything which is going permanently to prevent the fullest possible use being made of these is to be condemned, unless it can be clearly shown that compensating advantages are to be gained. The author has not indicated what these compensating advantages are. Busbar short-circuits have been very rare in the past, and with improved construction should be less likely to happen in the future, so that not much risk is incurred by leaving out the busbar section reactances until such time as the advisability of inserting them has been fully demonstrated.

Dr. C. C. Garrard: The author has shown clearly in his paper how the use of reactance had rendered possible the very large power-houses and electrical supply systems which were thought to be out of the question a few years ago. Moreover, he brings out the very dangerous condition in which a congested supply system may find itself at the present day owing to its rapid growth during the period of the war. The question of the value of short-circuit currents and the

capacity of the protective gear to deal with them is of extreme interest and one very little understood. The problems in connection therewith arise in many and varied places, and some operating engineers certainly want educating in this subject. As regards the location of the reactances, and looking at the subject from the general point of view, it would appear that the author advocates a sufficient reactance in the generator circuit coupled with sectionalizing reactances (i.e. reactance in parallel). Reactance coils in the feeders he deprecates, but he relies for series reactance upon the inherent reactance of the system, suitably arranging the feeders, etc., to this end. In this connection the author's remarks as regards the construction of reactance coils are interesting. I think there can be no doubt that the type of apparatus shown in Fig. 26 is the last thing any engineer would install in his station if he could possibly avoid it. I refer particularly to the exposure of such a large amount of bare metal at high voltages. I am sure that if the whole thing were put in a steel tank and filled up with oil it would be a much better arrangement. I cannot agree with the author's remark that it is an advantage to employ a design in which all parts are fully open to inspection. Such an argument could apply equally well to an oil-filled transformer, which is one of the safest pieces of electrical apparatus. If the reactance coil be in a steel tank, however, it is necessary to provide it with some kind of an iron core, and this renders the arrangement difficult for feeder reactances. With a feeder reactance the short-circuit current may be, say, 30 times the normal full-load current through the coil. With this large short-circuit current there is danger of the iron circuit, if such be used, becoming magnetically saturated, with the result that although the current will be increased 30 times yet the reactive effect will not have increased anywhere nearly to the same extent. Thus, the protective effect as regards short-circuit compares badly with the unavoidable reactance drop at full load. For busbar and generator reactances, however, the short-circuit current will not generally exceed 10 times the normal current, and this should allow iron-clad coils to be used. The author's conclusion that the limiting feature in regard to the extension of supply systems lies in the distribution system rather than in the generating station is interesting. I would not, however, go so far as this. Certainly a limit is reached if unsuitable distribution apparatus be used. I think the truer statement is that the trouble can be overcome in the distribution system by an improvement of known apparatus, and thus as far as this is concerned the wished-for extensions of the system could be arranged without reactances. It might, of course, be more economical to install reactances, and this can only be settled by knowledge of the particulars of the individual case. My point is that as far as the distribution is concerned it is possible to do without reactances. As regards the generating station, however, I think it is not possible and that reactances are absolutely necessary. Thus, the true limiting feature lies within the generating station. On page 270, in discussing prospective developments, the author states that machines and transformers will be regarded as one unit, all switching being carried out on the high-tension side. I am interested in this, as I believe I am correct in saying that in one large city in the Midlands the opposite has been arranged for on 30,000-volt lines. I should like to congratulate the author on the curves in Figs. 6, 15, 16, etc., and the argument on page 275 is particularly happy in which he shows how it is possible to build a 100,000-kw. plant in which the conditions will be not more severe than the present-day plant of one-third the capacity. I think, however, that Fig. 10 of the star design of busbars and reactances might be made a little clearer, as it looks at first sight as if it were a case of group feeders. I also think it would be an improvement if Figs. 12 and 13 could show the feeder circuits. As regards Fig. 9, I should think that generally the arrangement on the right-hand side for the less important circuit will be as expensive as that shown on the left-hand side for the important circuit. I suggest, therefore, that the left-hand arrangement would be the better under all circumstances. I agree with the author's remarks regarding large oil switches, that each phase should be in a separate stone or brick cell as in Fig. 7. I should like to ask as regards Fig. 7 whether the main current-carrying contact is above the oil pots in the open air; if so, I should like to ask whether this is considered a desirable arrangement. An objection has also been raised in some quarters as regards the type of switch shown in Fig. 7, in that the moving contacts move upwards in the oil and thus the head of oil is continually diminishing during the operation of breaking circuit. In comparing this with the type of switch shown in Fig. 30, one sees that in the latter the opposite is the case, in that the moving parts of the switch move downwards and thus the head of oil increases. Moreover with the type of switch shown in Fig. 30 the rush of current on short-circuit tends to open the circuit more quickly by increasing the repulsive force tending to press the moving contact downwards. I agree that the type of isolating switch shown in Fig. 29 is very bad. This is especially so if the supporting porcelains are fixed, as is sometimes the case, on an iron base. I think, however, I am correct in saying that this type of switch has been superseded by all up-to-date makers in favour of that shown in Fig. 31. I should like to raise a question as regards the two formulæ given on page 289. It seems to me that if d becomes infinitely small the force becomes infinitely large. This does not seem to be quite right. In conclusion I should like to ask the author whether the use of differentially-wound reactance coils is likely to become general. These have been introduced in the United States. It has seemed to me, however, that the complications thereby introduced would hardly be worth while.

Mr. R. Orsettich : The author in discussing the subject of protecting large power systems has given us a description of the American practice in large reactances. Whilst this is almost unavoidable because it is only in the States that the development of the power supply companies has reached the limits which the author discusses, one must not lose sight of the fact that other conditions which gradually led to such development do not obtain here, nor is there any probability of a change in the same direction. Notable differences

are:—(*a*) The overhead transmissions, which are essentially due to the long distances covered and over relatively less densely populated districts. (*b*) The main-line traction systems fed from the same stations which supply power and light. (*c*) The large use of synchronous converting sets, which enables them to generate with comparatively high power factor. In the question of the power factor of the load lies one of the most important points to be considered when discussing the advisability of increasing any particular generating system to the magnitude of those discussed in the paper: because such an increase in its turn might require for the safety of its operation the employment of the reactances between various generating stations linked together. In transferring lead from one section to another, the regulation of the system will be very bad owing to these reactances, unless the power factor is fairly good; on the other hand, how could the power factor of systems like the one of Birmingham or of Sheffield, which distribute alternating current to small consumers, be improved to admit their being supplied by one or more super-stations or linked up to another system through reactances? The adoption of a larger number of synchronous converters to improve the power factor from, say, 0·6 to 0·8 or 0·9 seems out of the question, as it would be a matter of creating new networks to absorb the direct-current power. The improvement by compulsory use of machines taking current at unity power factor would be the only correct course to adopt, but it would somewhat reduce the expansion of electric driving in favour of other systems, and would prove very slow, so that many years would elapse before the improved conditions would be obtained. It appears, therefore, that the improvement of the power factor in the large distributing systems as they exist over here must be obtained by means of large rotary condensers, supplying wattless current to balance the magnetizing current of the transformers, induction motors, and reactances. These rotary condensers are very expensive machines in relation to their output, and are also very costly to run; they also represent a dead loss to the company, which must be charged against the benefits claimed by the running of the large stations.

Mr. W. Wilson: There is one reason why I think the paper is of special interest, namely, that the greater portion of it deals with a simple piece of apparatus with no moving parts or other complication to get out of order or to cause expense. It is certainly a welcome change after the other developments of power-house design, which are rendering our stations not so much generating plants, as collections of elaborate apparatus, a large part of which is devoted to what may be termed "throttle-valve" duty. It is to be hoped that an extension of this principle will be possible in the near future, to replace at least a part of the complicated apparatus that is adding to the prime cost and the upkeep of our stations at present. There are a few points in connection with the external effect of the ampere-turns about which I should like to ask the author. It seems clear that the presence of an iron circuit is a drawback to a current-limiting reactance. The ideal state of things would be a device with no reactance at normal loads, but with a high one when overloads occur, a combination that seems unattainable. With an iron circuit, the permeability of which will fall off very considerably as it is supersaturated by a short-circuit current flowing in the coil, we have the reverse effect. These reactances therefore have in general to find an air path for their flux. Now what I should like to know is the extent to which the passage of this flux is felt in the vicinity. For example, it is conceivable that a portion of the iron framing of the building might come within the field, and trouble might be caused thereby in several ways. To begin with, the magnetic circuit would no longer be entirely an air one. Mechanical forces of attraction are possible. Also any mass of metal near by might offer itself as a short-circuited secondary. There is also the possible interference with meters, though modern instruments should be free from this risk. It would be interesting to know the precautions, if any, that are necessary to obviate these actions. The only example of the use of reactances which I have come across was one in which these coils were located under the switchboard gallery and alongside a wall of a ferro-concrete building. The amount of metal in such a structure is small, but still it might produce serious results if the reinforcement were to develop a high temperature through eddy currents. Probably the reactances being arranged in groups of three permits the phases largely to neutralize one another as far as stray flux is concerned, and as there seems little possibility of the single-phase system being revived for large schemes, this will keep the action from becoming serious. The iron tank proposed by Dr. Garrard would act as a screen for these stray lines if it contained all three reactances belonging to one machine. I must confess I do not understand the emphatic importance that the author attaches to the exposed nature of the pattern in Fig. 26. In a reactance we have the simplest appliance known to electrical engineering, which must on that account possess the maximum of reliability. Yet while transformers, armatures, lightning arresters, and other delicately constructed protective devices, and extra-high-tension switches are all enclosed, this one is left bare. It seems to me that the danger attending the exposure of these high-tension conductors is a definite weakness, and that some kind of cover is not only justified but necessary. With regard to the external main contacts of the oil switch in Fig. 7, I should like to ask whether signs of arcing are experienced at these points when overloads are being broken. If it is certain that one circuit may be suddenly, yet quietly opened, because a parallel one still remains closed, then this method is correct. Yet it is an everyday occurrence for a tramcar to arc violently at one wheel which is going over a stone, while as many as seven others are apparently making good contact in parallel with it. Arguing from this analogy, the practice referred to would appear somewhat risky, although of course I am aware it is followed rather extensively.

Mr. E. B. Wedmore (*in reply*): There is liability of a little misunderstanding as to what I have recommended, because it has been impracticable to deal within the limits of one paper with the possible combinations of generating stations and local conditions

met with in practice. What I have done is to work out each application of reactance to its logical limit, and the results show that so much can be done in such a variety of ways that in any particular case we have considerable latitude for dealing with local conditions without necessitating overstraining the plant or the use of apparatus excessively costly. It must not be supposed that where there are five 100,000-kw. stations interconnected I would advocate to spare machines of the largest size, or 25 distributing sections.

If one can do without artificial reactances, and this will often be the case, we may gladly omit them, but where big developments are pending it is necessary to take a long view. The distributing system may be sectionalized by pre-arrangement as it grows, but if no provision is made, the time may come when it is desirable but no longer commercially practicable.

In the Birmingham district some of the apparatus has already been subjected to conditions considerably more severe than were originally contemplated, and as development proceeds it is not going to be easier to avoid this. One has to consider also whether the losses accompanying the low power factor introduced by the use of 4 per cent feeder reactances are not greater than those due to the slight deterioration of load factor which may accompany sectionalizing.

I do not agree with Dr. Garrard's generalizations on the use of reactances. Here in Birmingham, a typical industrial area, where the concentration of power and the number of small users are large, Mr. Forrest is asking for 4 per cent feeder reactance to protect the small apparatus, but is quite happy about the generating plant. This is what I anticipated in saying that the limitations were in the distributing system.

Whilst the best modern transformers are reliable, many engineers would not endorse Dr. Garrard's statement that transformers are amongst the safest pieces of apparatus. If transformer designers could only employ the simple and safe construction shown in Fig. 26 they would be only too glad to do so.

When switches of the type shown in Fig. 7 are designed for large currents, the main contacts are brought outside the oil pots. Some designers have attempted to keep the main contacts under oil. This is quite unnecessary and introduces obvious difficulties in obtaining high speed and clean break. If in Fig. 7 the contacts under oil are suitably designed, there is no difficulty in adequately protecting the main contacts, and in fact designs introduced many years ago for the purpose have given uniformly satisfactory service. The electromagnetic stresses tend to accelerate the contacts in this type of switch just as much as in that shown in Fig. 30. With a switch on the lines of Fig. 7 the rupturing capacity could be increased if the parts were turned upside down; but the increased cost, and other disadvantages of a construction to obtain this, show that the better course is to build a larger switch. These switches are already in use in sizes large enough for the super-stations contemplated.

Referring to the formulæ given on page 289, fortunately we do not have to use devices in which d is infinitely small, so we do not have to contend with the infinitely large forces due to the infinitely large fields which would surround infinitely small conductors if they carried current.

The improvement of the power factor in large systems is a subject worthy of full discussion and affording considerable scope for new developments.

Many large reactances have been built on the lines of Fig. 26. Stray fields present no difficulty after space has been allowed for inspection all round the structure. The reactances are of course enclosed in brick or concrete cells, but ferro-concrete can be employed. Indicating instruments are not likely to be mounted on them or near enough to be affected, even on short-circuits.

DISCUSSION ON "GAS FIRING BOILERS."*

Newcastle Local Section, 4 February, 1918

Mr. A. H. W. Marshall: I think that, in spite of the author's favourable comments on the results to be obtained with Lancashire boilers, this type of boiler will be eventually superseded by the water-tube boiler on account of the higher steam pressure demanded. Further, I do not agree with him that any type of boiler can be worked efficiently with unclean gas, at any rate in this district. My experience is that it is impossible to keep water-tube boilers clean by means of a steam lance or other similar form of dust-removing gear. I have come to the conclusion that the commercial development of power production from blast-furnace gas on a really comprehensive scale is not possible unless the dust is first removed from the gas. Whether this should be done by a wet or a dry process of cleaning depends upon the amount of water present and the effect of this water on the efficiency of combustion. The author has dealt with the latter point, and it would be of value if, in the discussion, we could be informed as to what amount of moisture is usually present in the gas coming from the ores smelted in the Middlesbrough district.

Mr. L. Taylor: I fully agree with the author as to the reliability of modern turbine sets. To his remarks in reference to water-tube boilers I would add that an overall efficiency of 86 to 87 per cent has been obtained from "Nesdrum" water-tube boilers when fired with coal and coke-oven gas. I agree with him that gas-fired boilers have now a greater future. With regard to the gas-cleaning of blast-furnace gas, the author does not enter into the advantages or disadvantages of dry or wet cleaning, but he mentions the necessity of cleaned gas or dry gas and that dry gas is more important than cleaned gas, with which statement I also agree from practical experience. It would be of much interest if someone connected with the experiments now being made in Clevcland would state whether the experiments by electrical precipitation for cleaning blast-furnace gas are proving satisfactory and cheap. Should that be the case, then the wet cleaning process is doomed. In regard to the suitability of gas for boiler firing, the author remarks that coke-oven gas is particularly suitable for firing water-tube boilers, and with suitable combustion arrangements evaporations of $5\frac{1}{2}$ lb. per square foot of heating surface can be obtained at the highest efficiency. I may add that we have obtained as much as $7\frac{1}{2}$ lb. with high efficiency with our type of boiler with vertical tubes. Respecting heat transfer, he says that one square foot of heating surface at right angles to the gas flow is about four times more effective than a similar area parallel to the gas flow at ordinary velocities of gas. The high evaporation obtained as mentioned above, i.e. $7\frac{1}{2}$ lb., was obtained from our water-tube boilers arranged with the gas flow at right angles to the tubes and with no baffling except fireclay tiles between the nests of vertical tubes. In my opinion the shape and size of the combustion chamber also play an important part in modern water-tube boilers. The author mentions that up-to-date boilers do not differ by more than 5 per cent at the outside in their results when coal fired when the same type of stoker is used. I do not agree with this statement. Take as an example the results of a test made about July last of one of our water-tube boilers, coal-fired with underfeed stokers:—

Normal evaporation 15,000 lb per hour from and at 212° F. No economizer.

Test evaporation = 17,000 lb per hour. Efficiency 73·7 per cent.

Test evaporation—13,000 lb per hour. Efficiency 75·5 per cent.

Test evaporation—20,000 lb per hour, say 70 per cent overload). Efficiency 71·7 per cent.

Evaporation per square foot of heating surface = 5·23, 4·0 and 7·83 lb.

The above boiler is also fitted with gas burners for blast-furnace gas. These are fixed above the stokers so that the change-over can be made without stoppage; also part coal and part gas-firing is used to suit the conditions. There are 16 of these boilers in one battery. So far as the boiler setting is concerned I agree with the author as to the importance of substantial brick-work for coal and gas-fired boilers. We now always recommend reinforced cement and have got very good results from this method. Painting the outside of the brickwork with suitable paint or tar is well worth the extra cost. I agree with the author that where steady gas pressure is available the up-to-date type of Bunsen burner gives the best results. At most iron and steel-works the gas pressure is intermittent unless gas-cleaning plant is installed, so that it does not pay to install a large number of expensive Bunsen burners. I believe the author introduced some years ago a very good flat type of burner on the Bunsen principle and it would be interesting if he could give us some results of this type of burner. I may say we fitted a number of flat burners of our own design from which we obtained excellent results and high efficiency, and owing to their construction fewer burners are needed per boiler.

Mr. A. Coulson: It is necessary to go back to the early stages of the iron trade to explain to some small extent the position of affairs to-day. Iron-works were established, and exist at the present time as iron-making establishments pure and simple, and working under these conditions there is available such a large amount of gas for which no outside use could be found that the question of its economical use has not been

* Paper by Mr. T. M. Hunter (see pages 57, 163, and 209).

seriously considered. An iron-works and steel-works combined is in a better position as the surplus gas has a market value and can be used to good purpose. It is only within the last eight or ten years that power companies have realized the enormous resources available from a blast furnace, and it has now become a paying proposition for ironmasters to use their gas in the most economical manner. Many huge combinations of iron and steel-works now exist, in addition to working arrangements with power companies. It is essential that the gas be clean, if it is to be economically used, and it is only by using this gas for outside purposes in such a manner as to cut out coal that it can be made to pay. The recovery of potash has become another asset to the ironmasters and will materially help to pay off the cost of cleaning. In this district a number of experiments have been made in connection with the electric precipitation of dust in blast-furnace gas. This I have been able to see in operation, and think that in the future there will be very great developments on these lines. The author is, I think, optimistic in regard to the efficiency of boilers, particularly of the Lancashire type. He talks of 80 per cent, but I am afraid 60 to 65 per cent is more like the figures we are able to obtain. The difficulty is due to the gas supply being intermittent and the pressure fluctuating. This makes it impossible to keep an accurate mixture, which is most essential if high efficiencies are to be obtained. It would be interesting to know what were the steam pressure and feed temperature when the efficiencies mentioned in the paper were obtained.

Mr. J. Wright: We have had a good deal of information recently on blast-furnace and coke-oven gas and I think we are all more or less converts to gas-cleaning and agree that the dry cleaning process should be adopted. The argument against cleaning, apart from the loss of sensible heat, is the capital cost of plant; and if dry cleaning by electrical precipitation does all that is expected of it we shall be much nearer to a solution of this much-discussed problem, as the sensible heat will not be impaired and the capital outlay should be lower. With regard to firing water-tube boilers with cleaned and uncleaned gas, the author says that the efficiency with uncleaned gas is certainly within 10 per cent of the efficiency with cleaned gas, provided a steam lance is used. This may be so for a day or two after the boilers have been cleaned, but from experience I know the comparison is not so favourable for the uncleaned gas after the boilers have been steaming for, say, one week, and if a steam lance is to be used to keep up the efficiency then it should be supplied with superheated steam. It is better to use no lance at all than one supplied with saturated steam. With wet steam the dust simply sets like cement on the tubes. In considering the efficiency of boiler plant we should not overlook steam transmission to engines, and in this connection I think the author might have put more emphasis on the fitting of superheaters to all gas-fired boilers. It is frequently contended that in the case of old plants the use of superheaters is not practicable, but it is usually overlooked that in the majority of cases the steam is carried a long way in the open and when it arrives at the end the whole of the superheat is lost. The saving on superheating is twofold. In the first instance the radiation losses will be greatly decreased and wherever the engines allow the use of superheated steam the consumption of steam per horse-power will drop considerably. In any case the superheater will act as an economizer and increase the overall efficiency of the boiler plant. The author says that the boiler which abstracts the heat most successfully from the hot gases is the most satisfactory for gas-firing, and he suggests several methods of increasing the hot surface of the tubes without increasing the water surface. With regard to water-tube boilers, it seems to me this could be done most efficiently by adopting the arrangement of cast-iron fin plates as fitted to the Foster superheater tubes. These plates need only be fitted to the generating tubes and would have a heat-accumulator effect in the event of fluctuating gas supply.

Mr. H. Crowe: I consider that from a national standpoint we should abstract all the valuable by-products from the coal, instead of destroying them by burning coal directly on the fire-grates of boilers. The method apparently most feasible at the present moment is to gasify the coal, recover the by-products, and burn the gas under boilers, the drawback to this method being the loss in the producer, where we get only about 70 per cent. of the heat value of the coal in the gas. Of course, by utilizing the sensible heat in the gas to pre-heat the air entering the producer, a somewhat higher efficiency can be obtained. In addition to the loss in the producer itself, there is also the cost of steam necessary for working the producer, as without steam the producer would become too hot. The value of this steam, which is considerable, must also be added to the cost of working the producer—and approximately as much as one ton of steam is used per ton of coal gasified, this cost being 1s. 3d. per ton at the colliery. The author has mentioned the Moore producer and the method proposed by Eldred, who suggested that boiler flue-gases containing, say, 15 per cent of CO_2 could be advantageously used for the absorption of heat, which occurs when CO_2 is reduced to CO in the presence of heated carbon. It is well-known that Mr. Siemens patented his new form of furnace many years ago (a large number of these furnaces have been erected and working in this district) in which a portion of the highly heated products of combustion are returned into the producer instead of all passing into the regenerators. Theoretically, this process should result in considerable economy and saving of steam. In a somewhat similar manner I proposed some years ago to return a portion of the highly heated products of combustion from a furnace working on pure coke-oven gas, and mix them with the incoming cold coke-oven gas, so that instead of pure cold coke-oven gas of high calorific value entering the furnace one would have a large volume of highly heated gas of a lower calorific value, which whilst more suitable for many metallurgical purposes would have no advantage for boiler-firing. It has occurred to me, however, that it would be a considerable advantage, where blast-furnace gas is available, to pass a certain amount of this gas through the gas producer, the gas entering above the grate

level. The result would be that the CO_2 in the blast-furnace gas would be split up and converted into double the volume of CO, with an absorption of heat, so that in all probability no steam at all would be required, and the resulting gas would be very much higher in CO and very much lower in hydrogen, and I should say this process would result in economy, whilst being a more economical gas for boiler-firing on account of the absence of hydrogen. It would be an ideal gas for metallurgical furnaces and would result in considerable economy and increased output of steel. The author also draws our attention very forcibly to the importance of the absence of excessive moisture in the gas, with which I heartily agree. I consider without preheating the air required for combustion producer gas will not give a temperature such as is required for economical boiler-firing, but immediately one heats the air, high temperatures are obtained. It is, however, necessary that the heat required for preheating the air should be obtained from the waste flue gases after they have left the boiler. The author has also shown the importance of properly mixing the gas and air. I have had experience with a furnace the gas and air ports of which were built similar to an ordinary steel furnace. The furnace worked on cold gas of about 160 therms per cubic foot and regenerated air; the resulting flame temperature was not high enough to reheat steel to a rolling heat. The ports were altered, so that rapid and complete intermingling of the gas and air took place; and with no other condition changed, the furnace immediately attained the necessary high temperature for rolling steel. I mention this as an example of the value of the proper mixing of the gas and air.

Mr. J. H. Harrison: I do not think the author makes it sufficiently clear as to when he is referring to the use of cleaned blast-furnace gas and when to the ordinary gas we use here. Figures are given of boiler efficiency or evaporation which are far beyond anything we can get with uncleaned gas, and in my opinion if we want to get anything like the boiler evaporation he mentions, we are bound to clean the gas. The whole of this district has now taken up the question of cleaning gas, and we shall not be satisfied until the whole of the gas is cleaned. That will revolutionize the whole system of gas-firing for boilers and stoves; and we are therefore in a state of transition between what we have been accustomed to and what we shall have to adopt in combustion chambers and stoves for the use of cleaned gas. The author mentions evaporations of 9,000 lb. per hour from Lancashire boilers. I think that is a very high figure, but it may be correct if he means with cleaned gas. I do not think it is possible to get it with uncleaned gas upon economical lines. I have got over 8,000 lb. myself, but I think the waste gases were very much hotter than they ought to be and I think this would be the case with the 9,000 lb. he speaks of, unless cleaned gas is used. In regard to water vapour in the cleaning of blast-furnace gas, I do not think that there need be any trouble, because it could be condensed by cold water, not necessarily in contact with it but, as Mr. A. Lennox Leigh pointed out (when speaking on "The Cleaning of Blast-furnace Gas for Boilers and Stoves" before the Cleveland Institution of Engineers on the 15th January 1918), by Green's economizers through the tubes of which cold water is circulated. If it is a question of water in the gas being detrimental, the only way to get the moisture out is to cool the gas by cold water. If we do this, the initial temperature of the gas will be lost. It is of no use trying to burn ordinary dirty gas inside the flue of a Lancashire boiler, for good results cannot be got from this method. The only alternative is to put a firebrick-lined combustion chamber outside and sacrifice the loss in respect of radiation and conduction. The author gives an instance of the air for combustion being brought through a tube through the centre of the flue of a Lancashire boiler, and he says it is wrong. But the heat is not lost. I gather from the paper that the heat is lost. Well, it is only taking it from one portion of the waste gases in order that a higher combustion temperature shall be obtained. There are several important points in regard to stoves. The heating of the air for combustion and also the introduction of air under pressure both tend to increase the temperature of the flame. Now that again brings one back to the old question as to using ordinary dirty gas or cleaned gas. With dirty gas we find that the temperature is quite high enough for the brickwork to stand with the dust adhering to the bricks, for the dust forms a flux and burns the brickwork. By putting the air under pressure we shall get a higher flame temperature and it will be of no use unless we have clean gas, for we shall burn our stoves. The question of heating the air for combustion by economizers is subject to the same criticism We must use cleaned gas.

Mr. C. H. Ridsdale: There is no subject to which science can be more advantageously directed than the burning of gas. From the author's remarks I am more than ever impressed with the vital necessity of greater regularity. If we want scientific advancement we must have greater regularity and precision in working. That is going to affect us throughout. We are looking for the moment upon the blast furnace merely as a power producer, or as a source of power which ultimately we can turn into electricity. But anyone who knows anything about blast furnaces knows how extremely irregular they are inclined to be in many respects, and if we are to get more power from them we must get more regular working in everything. Mr. Marshall had said he would like to know the average moisture content of blast-furnace gas in this district. There is no such thing as a representative average because we have furnaces for so many different qualities of materials. In making iron for basic purposes, for instance, we sometimes get three or four times as much moisture in the gas as at other times, i.e. a 300 to 400 per cent variation. But if we cleaned the gas, whether it were by the dry or wet process, two great advantages are obtained. First, we get the moisture fairly uniform and, secondly, we start with a uniform temperature. By taking uncleaned gas a very great fluctuation in temperature may result. Some furnaces perhaps give off gas at 200° C., others perhaps at 400° to 500° C., so we get enormous fluctuations in moisture in these uncleaned gases, but when it is cleaned, as is

necessary in the Halberg-Beth process, we get down at the finish to something like 60 or 70 C., or in the case of washed gas 60° F., but in both cases we get down to comparatively low temperatures and thereby to fairly low moistures. I have had a good deal of experience with washed gases for stove purposes and there is no question about the great advantage, first to the stoves themselves and, secondly, to the burning of the gases. The very first effect of getting 2 cubic ft. of gas concentrated into 1 cubic ft. is the tendency for workmen to use too little air; but once that difficulty is surmounted, and also the difficulty of precipitation of the mechanically suspended moisture (apart from water vapour), then it becomes an excellent fuel which we can regulate more readily than the natural gases, i.e. uncleaned. The question of suspended moisture does not seem to have been mentioned, but in beginning with the wet process it is an important point because we are dealing with such large volumes of gas that the velocity (which is great) tends to carry along a large amount of mechanically suspended water vapour, and until we have precipitated the mechanically suspended moisture there will be trouble in the stoves. Of course all that is now being successfully overcome.

Mr. P. S. Thompson: The author says that the choice of burner is more important than the choice of boiler, but boilers being primarily intended for the use of solid fuel are not all equally suitable for gas-firing—some fit in with the altered conditions better than others. Coal-firing has an advantage over gas-firing because radiation from the glowing bed of fuel plays an important part in the transfer of heat to the evaporating surfaces and in supplementing the heat-radiating action of the brickwork lining of the combustion chamber. With coal-firing, therefore, more of the radiant energy of the process of combustion is given back, thus raising the temperature at which the thermal balance of the process is attained. As Mr. Marshall remarked, the conservation of fuel values has become largely a matter for electrical engineers. Mr. Marshall in his recent Address to the Newcastle Local Section* showed how the processes in a self-contained coke oven and iron and steel-works could be made almost self-supporting from a thermal point of view if full advantage were taken of all possible heat economies. The present paper forms a valuable contribution to our knowledge of how this can be done and, further, indicates how processes although separated geographically can be brought together electrically, the surplus energy from one process thus being passed on to another as required. Thinking of the recent report of the Coal Conservation Sub-committee it seems doubtful if gas-firing of boilers will have quite the future importance that the author believes, although gas-heating in general will attain a wider application. Large quantities of coke of various kinds will be produced and uses will have to be found for this, the most probable being that of firing boilers.

Mr. T. M. Hunter (*in reply*): I have been very much interested in Mr. Taylor's remarks regarding his experience with gas-fired boilers. In so many ways they corroborate my own experience. As regards the very high evaporation of 7½ lb. per square foot of heating surface by means of coke-oven gas, quoted by Mr Taylor, this figure depends on the type of boiler used The figure of 5½ lb. per square foot of heating surface which I have quoted was for two large Stirling boilers working at their normal load The gases left the boilers at a temperature of 240° C, so that the last range of boiler tubes was acting practically as an economizer, although the evaporation there was being taken as part of the whole evaporation of the boiler If there had been only two banks of tubes, and the hot gases had then gone to an external economizer, the evaporation per square foot of heating surface in the boiler would have been brought out at a much higher figure.

Mr. Coulson has asked for information with regard to the use of high pressure in gas burners, after the manner of oil burners, in order to spray the gas and air intimately together The objection to the use of high gas pressures is the cost of attaining these pressures for the huge volumes of gas with which we have to deal. If we could provide gas cheaply at a high pressure, it would be possible to design very efficient burners to mix it intimately with the necessary air. In reply to Mr. Coulson's question as to the conditions of test where high efficiencies have been attained with blast-furnace gas, I give the result of a test on a Stirling water-tube boiler in Germany, running on cleaned blast-furnace gas The boiler had 3,770 sq. ft heating surface, the superheater 1,078 sq. ft., and there was an economizer fitted The test lasted for 8 hours, and the steam pressure was 198 lb. per square inch. The gas was of 114 therms per cubic foot, and the composition, CO_2—5·8 per cent, CO—30·8 per cent, CH_4—0·6 per cent, H_2—6·8 per cent, N_2—56 per cent, (theoretical CO_2 in waste gases 22·2 per cent). The gas burned per hour was 2,706,000 cubic ft. water evaporated per hour, 19,800 lb., equal to 5·28 lb. per square foot of heating surface The flue-gas temperature after boiler was 405·4° C, and after economizer 206·5° C, and the average analysis, CO_2—21·5 per cent, O_2—0·9 per cent, CO—0·3 per cent The balance sheet showed

Overall efficiency	..	79·5 per cent
Chimney loss	..	8·0 ,,
Radiation and other losses	..	12·5 ,,

A little more might be said with regard to the cleaning of gas. Any of the three systems of cleaning gives the gas quite sufficiently clean for efficient use in firing boilers. The wet cleaning process gives the gas fully saturated with water at about atmospheric temperature, and in addition there is a fine spray of water carried mechanically in the gas. The latter may amount to a considerable weight of water per cubic foot of gas, and all this water has to be evaporated, raised to the flame temperature, and sent up the chimney at the temperature of the waste gases. The effect of this is to waste a considerable amount of heat as latent heat in evaporating this water; then the flame temperature is lowered by the loss of this heat, and by the dilution of the products of combustion with this water vapour, for

* See page 23.

which reason the efficiency of the heat exchange is reduced; and the latent heat, and sensible heat above atmospheric temperature, are lost up the chimney. If we add to these losses the loss of all the sensible heat in the gas, which occurs in the washing, and the large amount of power required for the plant, we find that the total cost, in power, of this process is quite considerable. In the Halberg-Beth process, the gas, as in the wet process, is delivered at a uniform pressure and temperature, and this is an important advantage of both processes. The temperature of the gas in the Halberg-Beth process is about 70° C. In very many cases the moisture supplied to the furnace in the ore and the coke is sufficient to saturate the gas at this temperature. The gas at 70° C. carries only some 2 therms per cubic foot of sensible heat, whereas if it is burned and the products of combustion pass to the chimney at 250° C., the moisture present in the gas is responsible for a loss in efficiency of $5\frac{1}{2}$ per cent, compared with the result to be attained by burning the same gas supplied at atmospheric temperature and saturation. The effect on the flame temperature is also serious, and is in addition to the loss in efficiency. If the gas is burned with 25 per cent excess of air, the theoretical flame temperature would be about 1,320 C.; and if supplied saturated at 70° C., the theoretical flame temperature would be reduced to about 1,090° C. At 100° C. the gas carries 3 therms of sensible heat per cubic foot, whereas the moisture carried at just under that temperature is three times as much as at 70°. The reduction in the flame temperature due to this additional moisture is still more serious. It is evident from these figures that it will not pay to retain these small amounts of sensible heat in the gas if the gas is found to be saturated with moisture at these temperatures. It will pay well to go in for further cooling of the gas. These remarks are specially applicable to the condition of the furnace load found in the winter, when coke and ore may carry a large proportion of moisture. It is much easier to arrange to cool the gas in winter, and probably the cooling apparatus could be safely cut out in the dry months of the year. In the Lodge electrostatic process of gas-cleaning, conditions are quite different. All the sensible heat in the gas is preserved, but, on the other hand, the gas is supplied to the boilers at constantly varying temperatures and pressures. From the point of view of high efficiencies in boilers and stoves, steady conditions are even more important than the retention of the sensible heat in the gas. Steady conditions could probably be attained most simply by the use of a gas holder, which would flatten out the variations in pressure and assist in giving more regular temperatures. In the gas cleaned by this process we find all the moisture put into the furnace, and at times this may be a very large amount. On the other hand, the sensible heat carried by the gas is much larger. At 200° C. it is 7 therms per cubic foot, at 250° C. it is 9 therms, and at 300° C. it is 11 therms. Again, the temperature of the waste gases leaving the boiler is little, if any, greater than the entering temperature of the gas if air or water economizers are fitted on the boilers. Thus the loss in the boilers due to moisture in the gas is that due to poorer transfer of heat caused by lower flame temperature; for the sensible heat carried away by the moisture in the waste gases is balanced by that supplied by the moisture in the live gas. The lower flame temperature is the result of the dilution of the products of combustion by the water vapour, and the results on the flame temperature are similar to those caused by excess of air in the burning gases, shown in the tables in the Appendix. Suppose a gas of 100 therms per cubic foot is supplied to the boiler at 250° C. It carries 9 therms of sensible heat per cubic foot, or in other words the total calorific value is 109 therms per cubic foot. If this gas carries 0·125 lb. of water vapour per cubic foot, and the products of combustion pass to the chimney at 250° C. and contain 20 per cent CO_2, the chimney loss by sensible heat is no greater than if a dry gas had been supplied. The theoretical flame temperature, however, would be 640° C., compared with 1,110° C., if the same gas had been cooled to atmospheric temperature and burned with the same excess of air. This is a most serious difference. In this particular case the flame temperature is so near the ignition temperature of CO (about 600° C.) that great difficulty would be found in burning the gas, even with such a small excess of air; and it could not be burned at all with much more air than this. It follows from this that if there is a large quantity of moisture in the cleaned gas, it may be necessary to sacrifice the sensible heat of the gas and to throw away even as much as 10 per cent of the calorific value, for the sake of getting combustion at a high temperature and to get adequate boiler outputs. These points all require to be considered, in addition to the cost of the plant and of the power to drive it, when buying a gas-cleaning installation for any particular set of gas conditions. The preheating of the air for combustion is a most important point in connection with gas-firing. If we supply air heated in economizers in the chimney flue, we save much of the sensible heat which would otherwise be lost. But what is much more important, we raise greatly the flame temperature, and there is no danger of water vapour being present in the preheated air to interfere with this temperature.

Mr. Crowe has emphasized the need of using preheated air, particularly with the poorer industrial gases, blast-furnace and producer gas. Preheated air has been largely used in this country in connection with coal-fired boilers, and excellent air economizers are made by British firms such as, for example, the Underfeed Stoker Company's air preheater. This country has supplied many plants of this kind to Continental works for use with gas burners. We have been so very far behind Belgium and Germany in the adoption of modern combustion arrangements that I know of no case in this country where air economizers have been fitted in combination with gas burners. I think that this is a development which will now come in very rapidly with the cleaning of gas and the demand for the utmost economy in its combustion. It is fortunate that gas burners are now available which can make full use of the best conditions which can be provided.

In reply to Mr Harrison, the evaporation of 9,000 lb. per hour from and at 100° C. in a 30 ft. × 8 ft. Lan-

cashire boiler was done with cleaned blast-furnace gas from a coal-fired blast-furnace, and the chimney gases were not at an excessive temperature, although far too hot for economical working. No economizer was fitted. As regards the possibility of burning uncleaned blast-furnace gas in the tube of a Lancashire boiler, I have not found the difficulty which Mr. Harrison mentions nor have I found the necessity of lining the tube with firebrick. By the use of gas burners, which allow the gas to be burned with a small excess of air, the flame temperature is so much increased that the complete combustion of large quantities of gas is satisfactorily attained.

Mr. Thompson has spoken of the proposed erection of large central power stations and the distribution of electrical energy from these. I should like to point out the great ease and economy with which gas can be distributed in large mains. The loss is exceedingly small. If gas were generated at convenient central stations and distributed to some of the best of our existing electric power stations, we should be able to save some of the heavy capital cost of new power stations, and we should also save in the serious cost and leakage losses of the new transmission lines which would be required from the large central electric power stations

REPORT OF THE COUNCIL FOR PRESENTATION AT THE ANNUAL GENERAL MEETING OF 30 MAY, 1918.

At this, the Forty-sixth Annual General Meeting of The Institution of Electrical Engineers, the Council present to the members their Report for the year 1917–18.

Membership of the Institution.

Statistics.

The changes in the membership since the 1st April, 1917, are shown in the following table :—

	Hon. Mem.	Mem.	Assoc. Mem.	Assoc.	Grad.	Stud.	Total
Totals at 1 April, 1917	8	1,483	3,528	481	401	712	6,613
Additions during the year :—							
Elected	1	11	81	13	47	122	
Reinstated	..	1	..	1	3	3	
Transferred to	..	28	51	1	32	..	
Total	1	40	132	15	82	125	
Deductions during the year :—							
Deceased	..	17	27	4	2	17	
Resigned	..	4	18	2	2	3	
Lapsed (Estimated)	..	12	49	7	12	53	
Transferred from	..	..	24	5	21	62	
Total	..	33	118	18	37	135	
Net Increase	..	..	..	..	..	..	54
Totals at 1 April, 1918 :—	9	1,490	3,542	478	446	702	6,667

In addition, 55 candidates for Associate Membership have been approved by the Council during the year for admission to that class on condition that they pass the Institution examination or otherwise satisfy the examination regulations. Of these, 1 is an Associate, 15 are Graduates, and 8 are Students.

Honorary Member.

The Council have pleasure in recording the announcement made at the Ordinary Meeting of the 22nd November last that they had elected Professor Augusto Righi, of the University of Bologna, to be an Honorary Member of the Institution.

Enemy Members.

The total number of former members who, on account of enemy nationality, ceased to be members under Clause (*a*) of Article 41 of the Articles of the Association is 42.

Admission of Generating Station Shift Engineers to Associate Membership.

The Council have adopted the following rule in regard to the admission of Shift Engineers as Associate Members :

Full responsibility for at least two years for the plant and staff in a power station or substation where 12 men (4 per shift) or more are employed, or for a section of the work (such as the boiler house or the engine room) in a station having not less than 2,000 kw. of load, will be accepted as complying with the requirement of employment in a "responsible position." In addition, the candidate must satisfy regulations as regards training and education as an Electrical Engineer.

This rule is only for the general guidance of the Membership Committee, who will consider each case on its merits.

Employment Register for Members Serving in H.M. Forces or Engaged on War Work.

The Council have decided to set up an Employment Register for the purpose of assisting members serving in H.M. Forces or engaged on war work in finding suitable employment when demobilization takes place. The necessary forms will shortly be issued.

Honours Conferred.

The Council record with satisfaction that His Majesty the King has conferred the following honours on members:—

Privy Councillor.

Major Sir Henry Norman, Bart., M.P. (Associate).

Baronetcy.

Sir Robert A. Hadfield, F.R.S. (Member).

G.B.E.

The Rt. Hon. Lord Moulton, K.C.B., F.R.S. (Member).

K.B.E.

Colonel A. M. J. Ogilvie, C.B., V.D., R.E. (T.) (Associate).

Professor R. Threlfall, F.R.S. (Member).

Knighthood.

R. T. Glazebrook, C.B., D.Sc., F.R.S. (Member).

C.B.E.

A. E. L. Chorlton (Member).
W. Duddell, F.R.S. (Member).
P. J. Pybus (Member).

O.B.E.

D. A. Bremner (Member).
A. D. Constable (Member).
C. Crompton (Member).
G. K. B. Elphinstone (Member).
M. B. Field (Member).
A. E. Hadley (Member).
W. J. Larke (Member).
J. McCaffery (Associate Member).
W. McClelland (Member).
L. Newitt (Member).
C. C. Paterson (Member).
N. B. Rosher (Member).
F. H. Royce (Member).

M.B.E.

E. R. Clarke (Associate).
J. F. Edmonds (Associate Member).
H. A. Nott (Associate Member).

Military distinctions have been awarded to members during the year as follows:—

Distinction	No. of Awards
C.M.G.	4
D.S.O.	15
Bar to Military Cross	1
Military Cross	45
Distinguished Service Cross	1
Military Medal	4
French Decorations	11
Italian Decorations	1
Mentioned in Despatches	53
Mentioned	6

The complete lists of names have been published in the *Journal* (vol. 55, p. 537; vol. 56, *Institution Notes*, No. 1, p. 3; No. 4, p. 15).

Roll of Honour.

Thirty members have been reported during the year to have given their lives in the service of their country, and their names and military ranks are set out in the *Journal* (vol. 55, p. 537; vol. 56, *Institution Notes*, No. 1, p. 3; No. 4, p. 15).

Other Members Deceased.

It is with the deepest regret that the Council have to record the death of Mr. W. Duddell, C.B.E., F.R.S., Past-President.

Mr. Duddell joined the Institution as a Student in 1894, became an Associate in 1897, an Associate Member in 1901, and a Member in 1904. He served on the Council as an Associate from 1901 to 1903 and as an Ordinary Member from 1905 to 1907. In 1909 he was elected a Vice-President of the Institution, and he became President in 1912, an office which he filled with great distinction for two years, retiring in 1914.

The Council have also to deplore the loss of the following members who have died during the year:—

Members.

Barry, Sir John Wolfe, K.C.B., F.R.S.
Cochrane, E. J.
Davis, J. P.
Erskine, E. J.
Hesketh, J.
Lorrain, J. G.
Morishima, K. M.E.
Porter, E. E.
Sayers, R. M.
Sellon, J. S.
Stone, W. H.

Associate Members.

Alexander-Todd, A.
Allan, J.
Anson, J. W.
Boyd, W.
Christian, E. A.
Dieppe, R. C.
Flynn, T. J.
Gauntlett, R. W.
Knight, B.
Mead, W.
Newton, E. W.
Stephens, H. G.
Strachan, J.
Teague, M. O.
Turner, C.
Williams, W. W.
Wilson, A.

Associates.

Aimack, E.
Fenn, E. J.
Ivor-Moore, T.

Proxy Voting.

The necessary additions to the Articles of Association to provide for Proxy Voting at Annual and Special General Meetings of the Institution were made at Special General Meetings of the Corporate Members held on the 17th May and 14th June, 1917.

Meetings and Papers.

During the past twelve months 16 Ordinary and 3 Special General Meetings and 22 Council Meetings have been held. The usual Standing Committees have met regularly, and there have also been meetings of other Committees appointed by the Council for the consideration of special matters, the total number of

Committee Meetings and Conferences held during the year being 112, as follows:—

Committee	No. of Meetings
Benevolent Fund	9
Finance	10
Membership	6
Papers	8
Patent Law	5
Research (including Sub-Committees and Panels)	20
Ship Electrical Equipment	6
Wiring Rules	4
Other Committees and various Conferences, which dealt with the following subjects: Disabled Sailors and Soldiers, Electrical Cooking and Heating, Electricity Supply, Electric Supply Employees, Enemy Submarines, Examinations, Fuel Oil, Increase of Membership, Lead Covered Conductors, Local Sections, Metric System, Model General Conditions, National Proving House, Patents and Designs Bill, Reserved Occupations, "Science Abstracts," etc.	44
	112

There have been 47 meetings of Local Sections, viz.

Birmingham	7
Dublin	6
Manchester	11
Newcastle	9
Scottish	6
Western	2
Yorkshire	6
	47

The following is a list of papers read during the Session 1917–18, in addition to which 4 papers not read at meetings were published in the *Journal*:—

Papers read at Meetings.

Author.	*Title.*
S. T. Allen, Member.	Address as Chairman of the Birmingham Local Section.
L. Andrews, Member.	"Overseas distribution of engineering appliances."
Ll. B. Atkinson, Member.	"The pros and cons of the metric system."
F. G. C. Baldwin, Associate Member.	"Telephone exchange transfers and their organization."
Dr. S. F. Barclay, Associate Member.	"The mechanical design and specification of the turbo-alternator rotor."
C. J. Beaver, Member.	Address as Chairman of the Manchester Local Section.
Dr E. P. Cumberbatch.	"Diathermy: the use of the electrical current to raise the temperature of the body in the treatment of disease."
Captain W. P. Digby, Member.	"Contract prices during demobilization."

Papers read at Meetings—continued.

Author.	*Title.*
R. H. Fletcher, Member.	Address as Chairman of the Western Local Section.
Dr. C. C. Garrard Member.	"Switchgear standardization."
W. A. Gillott, Associate Member.	"Electrical cooking as applied to large kitchens."
T. M. Hunter.	"Gas firing boilers."
C. M. Jacobs.	"Electrical signalling and control on railways."
Dr. R. Knox.	"Single-impulse radiography (instantaneous): its limitations and possibilities."
W. Lang, Member.	Address as Chairman of the Yorkshire Local Section.
E. C. McKinnon, Associate Member.	"Large batteries for power purposes."
Professor E. W. Marchant, Member.	"Some transient phenomena in electrical supply systems."
A. H. Marshall, Member.	Address as Chairman of the Newcastle Local Section.
A. Page, Member.	Address as Chairman of the Scottish Local Section.
J. H. Shaw Associate Member.	"The use of high-pressure and high-temperature steam in large power stations."
A. J. Stubbs, Member.	"A case for the adoption of the metric system (and decimal coinage) by Great Britain."
W. Tailow, Member.	"Electricity supply in Dublin and the surrounding districts."
C. Turnbull, Member.	"A British electrical proving house."
Major O. T. O'Kelly Webber, Member.	Address as Chairman of the Dublin Local Section.
E. B. Wedmore, Member.	"The control of large amounts of power."
C. H. Wordingham, President.	Inaugural Address.

Other Papers published in the Journal.

Author.	*Title.*
B. Wetbourn Member.	"The properties of electrolytic copper—modulus of elasticity."
Professor E. Wilson Member.	"The magnetic shielding of large spaces."
W. Wilson, Associate Member.	"The electric lighting of ecclesiastical buildings."
G. N. Wright, Associate Member.	"Pressure drop curves for copper overhead lines."

During the Session, the President visited the Birmingham, Manchester, Newcastle, Scottish, and Yorkshire Local Sections and addressed the members.

Kelvin Lecture.

The ninth Kelvin Lecture was delivered by Professor Magnus Maclean, Member, on the 7th February, 1918, the subject of the lecture being: "Kelvin as a Teacher."

Premiums.

The following premiums for papers have been awarded by the Council:—

The Institution Premium (value £25).

E. B. Wedmore. "The control of large amounts of power."

The Ayrton Premium (*value £10*).

E. C. McKINNON. "Large batteries for power purposes."

The Fabie Premium (*value £10*).

F. G. C. BALDWIN. "Telephone exchange transfers and their organization."

The John Hopkinson Premium (*value £10*).

Dr. S. F. BARCLAY. "The mechanical design and specification of the turbo-alternator rotor."

The Paris Premium (*value £10*).

Dr. C. C. GARRARD. "Switchgear standardization."

An Extra Premium (*value £10*).

W. A. GILLOTT. "Electrical cooking as applied to large kitchens."

An Extra Premium (*value £10*).

T. M. HUNTER. "Gas firing boilers."

An Extra Premium (*value £10*).

C. M. JACOBS. "Electrical signalling and control on railways."

An Extra Premium (*value £10*).

A. E. MOORE. "A new concentric standard dynamometer wattmeter for heavy currents: and concentric non-inductive standards of low resistance."

An Extra Premium (*value £10*).

J. H. SHAW. "The use of high-pressure and high-temperature steam in large power stations."

In view of the reduced number of papers read this Session at meetings of the Students' Sections no Students' premiums have been awarded, but the papers read will be taken into consideration at the next award of Students' premiums.

STUDENTS' SECTIONS.

Eight meetings of the Students' Section have been held in London, at which papers were read and discussed. At the opening meeting an address to the Students was delivered by Sir Oliver Lodge, D.Sc., F.R.S., on "Astronomical Applications of the Electrical Theory of Matter."

The Manchester Students' Section has held four meetings.

No meetings of the Newcastle and Scottish Students' Sections have been held.

SCHOLARSHIPS.

In view of the absence of a large number of Students on Naval or Military Service, the Council have again decided not to award the David Hughes and the Salomons Scholarships this year.

ANNUAL DINNER AND ANNUAL CONVERSAZIONE.

On account of the War these functions have not taken place, but informal dinners of the members have been held after the Ordinary Meetings in London.

LOCAL HONORARY SECRETARY AND TREASURER ABROAD.

The Council have appointed Mr H. R. Harper to be Local Honorary Secretary and Treasurer of the Institution for Victoria, in succession to Mr. J. Hesketh. The Institution is indebted to Mr. Hesketh for his valuable services in promoting its interests.

LOCAL SECTIONS.

The Council have received several valuable suggestions from the Committees of the Local Sections for increasing the usefulness of the Institution. These are being considered by a Committee consisting of the President, 7 Members of Council and the Chairmen and Secretaries of the Local Sections.

WIRING RULES.

As mentioned in the last Report, it is not proposed to undertake a further general revision of the Wiring Rules until after the War, but where the Council are of the opinion that any clauses in the present edition of the Rules require amendments owing to the development of the industry, the necessary alterations will be made. In particular the rules relating to lead-covered conductors and the question of earthing are receiving attention.

At the suggestion of the Engineering Standards Committee the Council have agreed to amend Rule 62 so that it does not apply to meters for currents up to 100 amperes made in accordance with the British Standard Specification for Consumers' Electric Supply Meters (E.S.C. Specification No. 37).

"SCIENCE ABSTRACTS."

The size of the volumes of "Science Abstracts" for 1917 shows some increase over that for 1916, the total number of pages being 1,136 as against 963 in 1916. The cost of the publication increased considerably, mainly on account of the very high cost of paper, but also in part on account of the higher charges for printing. The net cost to the Institution was £513 as compared with £291 in 1916.

BOARD OF SCIENTIFIC SOCIETIES.

The Institution has made two contributions of £50 each towards the expenses of the Board of Scientific Societies.

REGULATIONS FOR THE ELECTRICAL EQUIPMENT OF SHIPS.

The Committee engaged in drawing up regulations for electrical installations on ships have not yet completed their work, but the first draft of the Regulations is ready.

Informal meetings of the Newcastle and Scottish Local Sections have been held to discuss the draft and to enable members interested to suggest amendments for consideration by the Council before the Regulations are actually issued. It is hoped in this manner to obtain the benefit of the experience of the general body of members in marine electrical work and so to render

the Regulations as perfect and generally acceptable as possible.

Standards will be set up in the Regulations for securing uniform conditions and interchangeability in connection with many of the articles now on ship installations, and in every case the standardization has been referred to the Engineering Standards Committee, who are issuing Standard Specifications dealing with the respective items. These Specifications will be referred to in the Regulations, in order to avoid overlapping of work and to ensure that standardization is effected by the body specially set up for that purpose. The co-operation throughout has been of the most intimate and cordial character.

Street Lighting Specifications.

The Standard Clauses for Street Lighting Specifications recommended in the Majority Report of the Street Lighting Specification Committee have been published in the *Journal* (vol. 55, p. 522), and also in pamphlet form. The Council hope that these may be found useful when the question of street lighting is reconsidered after the War.

Examinations.

On account of the War, no examinations have been held.

Research.

Insulating Materials.

The Panels set up by the Council to organize researches and draw up standard specifications in connection with porcelain, ebonite, mica and micanite, fibrous materials, insulating varnishes, and composite materials, have made considerable progress, and provisional specifications have been drafted for several of the above materials.

In the case of composite materials, arrangements have been made for carrying out researches at a number of Universities and Technical Colleges with a view to determining the values to be inserted in the draft Specification; and in connection with this research it has been necessary to obtain a set of steel moulds in order that test-pieces may be prepared of the special shapes described in the Specification. This research is of particular importance in connection with the insulating materials used for magneto distributors—such materials previous to the War were mainly obtained from enemy countries.

The British Electrical and Allied Manufacturers' Association are actively co-operating with the Institution in this matter and the Specifications are the result of their joint labours.

In connection with the applications made by the Institution and the B.E.A.M.A. to the Department of Scientific and Industrial Research for grants for this research, the Department appointed in May 1917 an Electrical Research Committee consisting of three members nominated by the Council of the Institution and three by the Council of the B.E.A.M.A. The functions of the Committee are to control the grants made by the Department and the contributions of the Institution and B.E.A.M.A., and to conduct and be responsible for the researches on Insulating Materials referred to above, in respect of which the Department has made a grant of £2,050 to the Committee. At the instance of the B.E.A.M.A. representatives, the President (Mr. C. H. Wordingham) was elected Chairman of this Committee and Mr. Rowell, Secretary.

Buried Cables.

Further progress has been made with this research, but results are not yet available for publication. The amount expended on the research in 1917 was £324, of which £296 was contributed by Electricity Supply Undertakings, the balance being defrayed partly by the Institution and partly out of a grant from the Research Department.

In addition to this expenditure, the Research Department has provided £750 towards the cost of a special machine at the National Physical Laboratory for the purpose of the tests.

It is estimated that the expenditure during 1918 will be about £750.

Insulating Oils.

The reports of six investigators who have been carrying out the following tests are nearly ready :

(1) Tendency to sludge.
(2) Loss by evaporation.
(3) Flash point.
(4) Viscosity at different temperatures.
(5) Chemical reactions.
(6) Density and coefficient of expansion.
(7) Cold test (solidification).

The question of publishing the results will depend upon the sanction of the Research Department being obtained.

The expenditure on this research during 1917 was £467, of which the Research Department contributed £421 and the Institution £46, and the balance of £249 out of a grant of £670 from the Research Department with interest amounting to £4, a total of £253, has been carried forward towards the expenditure during 1918, an estimate of which is not yet available.

Electricity Supply.

In March 1917 the Board of Trade appointed a Committee " to consider and report what steps should be taken, whether by legislation or otherwise, to ensure that there shall be an adequate and economical supply of electric power for all classes of consumers in the United Kingdom, particularly industries which depend upon a cheap supply of power for their development."

The Council offered their assistance to the Committee and later received an invitation to nominate a representative to give evidence. The evidence to be submitted was prepared by the Electricity Supply Committee of the Council, and after it had been approved by the Council, Mr. C. P. Sparks, who then held the office of President, attended before the Committee and gave evidence on behalf of the Council.

National Service.

Members on Naval or Military Service.

From returns supplied by members it appears that the number of members serving or having served in the Navy or the Army since the outbreak of the War is 1,869, namely, 175 Members, 857 Associate Members, 84 Associates, 152 Graduates, and 601 Students.

A Greetings Card was again sent last Christmas in the name of the Institution to its members on active service.

Employment of Disabled Sailors and Soldiers.

The training of disabled sailors and soldiers as sub-station attendants which had been carried out under the auspices of the Institution at the Northampton Polytechnic Institute, Clerkenwell, E.C., since June 1916 was taken over by the War Pensions Statutory Committee in June last.

The following are the statistics for the 17 courses up to the end of March last:

Number of applications for admission ..	417
Number actually commencing the course	285
Number approved for employment ..	254
Number actually placed	245
Number of applications from employers, over	450

Reserved Occupations.

During the period under review representatives of the Council had interviews with the Reserved Occupations Committee and the Director of Labour Supply to the Ministry of Munitions in regard to the calling-up of more men from Electricity Supply Undertakings for military service. In this connection the Institution had the benefit of the co-operation of the Incorporated Municipal Electrical Association, the Incorporated Association of Electric Power Companies, the Conference of Chief Officials of London Electric Supply Companies, and the Provincial Electric Supply Committee of the United Kingdom.

Institution Premises.

The portion of the Institution building occupied by the Institution was taken over by H.M. Office of Works on the 6th April, 1917, and the offices of the Institution were transferred on that date to 1 Albemarle Street, W. 1.

By kind permission, the Ordinary Meetings of the Institution have been held at The Institution of Civil Engineers.

Fuel Oils.

A Committee was appointed by the Council on the 13th December, 1917, to consider the question of the supply and prices of fuel oils to Electricity Supply Undertakings. After two meetings had been held, a deputation of the Committee waited upon the Controller of Munitions Mineral Oil Production. The result was highly satisfactory, and the Controller decided that a Committee of the Diesel Engine Users' Association should, in co-operation with him, arrange for the supply of suitable oils, etc., to Electricity Undertakings.

On the invitation of the Association it was agreed that the Institution should nominate three representatives to serve on this Committee, and Messrs. A. H. Dykes, W. Fennell, and J. C. Wigham have been nominated by the Council for that purpose.

As a further result of the Deputation a circular letter was addressed by the Controller to users of Diesel engines, advising the adoption of tar oils under licence from the Department, and offering to assist in adapting Diesel engines for the consumption of tar oils, by obtaining priority for the necessary material and engine alterations.

Patent Law.

A private meeting of members of the Institution was held on the 28th February, 1918, to consider the provisions of the Patents and Designs Bill. The views expressed at the meeting and suggestions for the improvement of British Patent Law (including an automatic moratorium for a period equal to that of the War) are under consideration by a Committee which has been specially appointed by the Council to deal with the matter. The Committee is in touch with other bodies interested in this question.

A deputation organized by the London Chamber of Commerce waited on the President of the Board of Trade on this question on the 12th March. The Chairman of the Institution Committee represented the Institution on the Deputation and took the opportunity on behalf of the Institution to urge the desirability of the above-mentioned moratorium.

Non-ferrous Metals Bill.

The following resolution passed by the Council in December last in regard to the Non-Ferrous Metals Bill was duly communicated to the President of the Board of Trade:—

> "That the Council of the Institution of Electrical Engineers welcomes the Non-Ferrous Metals Bill, approves its principles and congratulates the President of the Board of Trade on its introduction. The Council representing an Institution whose members are interested so widely in the supply of non-ferrous metals, unanimously supports this measure designed to keep the control of the supply of these essential metals in British hands."

Metric System.

At a conference of representatives of the Institution, the British Electrical and Allied Manufacturers' Association, the Cable Makers' Association, the Tungsten Lamp Association, and the Battery Makers' Association summoned by the Council, and held on the 25th March last, the following resolution was unanimously passed in regard to the use of the Metric System by the Engineering Standards Committee:—

> "That all electrical standard publications shall primarily be in inch measurements, and may give in parallel columns or supplementary tables the metrical equivalents.

"Provided always that if the manufacturing interests in the trade concerned express a desire for it to be so drawn up, a Sub-Committee or Panel may draw up a standard table either in metric measures alone or in metric measures with inch equivalents in parallel columns, or in metric measures with a supplementary table of inch equivalents.

"In such a case a report to this effect shall be submitted to the Sectional Committee when the standards come before them for ratification."

Engineering Training Organization

The Council are taking an active interest in the proceedings of the Engineering Training Organization and are contributing £100 to its expenses for the current year.

The objects of the Organization are set out in the following Resolution which was passed at the Inaugural meeting, held on the 25th October, 1917, at which it was decided to set up this body:—

"That this meeting of engineers and educationalists is of opinion that a need exists for improvement in and better co-ordination of engineering training, and considers that some form of central organization is a desirable means to this end. It is therefore resolved that a representative committee with powers to add to their numbers be appointed to initiate means that will give effect to this principle of a central organization, and that the first members shall be representative of the following bodies:—

Institution of Civil Engineers.
Institution of Electrical Engineers.
Institution of Mechanical Engineers.
Institution of Naval Architects.
Iron and Steel Institute.
Liverpool Engineering Society.
South Wales Institute of Engineers.
Institution of Civil Engineers of Ireland.
Institute of Metals.
Institution of Municipal and County Engineers.
Institution of Gas Engineers.
Institution of Mining Engineers.
Institution of Mining and Metallurgy.
The Technical Committee of the Motor Industry.
The Federation of British Industries.
The British Engineers' Association.
The Board of Education.
The Headmasters' Conference.
The Incorporated Association of Headmasters.
The Association of Technical Institutes.
Junior Institution of Engineers.
North-East Coast Institution of Engineers and Shipbuilders.
Institution of Engineers and Shipbuilders in Scotland.
The British Electrical and Allied Manufacturers' Association.
The Universities and Technical Colleges of University rank.
The Joint Committee of the Aeronautical Society and Society of British Aircraft Constructors."

The President, Mr. C. H. Wordingham, who was intimately associated with the movement in its early stages, has been nominated by the Council to be the representative of the Institution on the Organization, and he has been elected Vice-Chairman of the Executive Committee of the Organization Council.

Electric Cooking and Heating

A conference of representatives of makers of the above, of supply undertakings and others, summoned by the Council, was held on the 20th February last to consider what steps can be taken to promote the advancement of cooking and heating by electricity. As the result of the conference, the Council have decided to appoint a Committee to prepare a detailed scheme for an Electrical Cooking and Heating Association. It is proposed to invite representative Associations to nominate members to serve on the Committee.

Board of Trade Order for Reduced Consumption of Electricity

In the early part of April the Council summoned a conference of representatives of supply undertakings to consider whether the Institution should take any steps in connection with the above. After consideration of all the facts, the conference decided to advise the Council to submit certain observations to the Board, and to urge that the Board when considering cases of excessive consumption under Sections 13 and 14 of the Order, should decide all such cases on the principle of whether or not the use made of gas or electricity subsequently to the promulgation of the Order has in fact assisted in the saving of coal in the particular premises in question.

Benevolent Fund.

The Committee of Management of the Benevolent Fund of the Institution report that on the 31st December, 1917, the Capital Account of the Fund stood at £4,642 3s. and the accumulated Income at £2062 12s. 2d. The donations and subscriptions to the Fund in 1917 amounted to £194 2s.

In the course of the year 14 grants were made amounting to a total of £197 15s.

The Accounts of the Fund, which are separate from those of the Institution, will be found on page 343 of volume 56 of the *Journal*.

Annual Accounts.

Excess of Income over Expenditure.—The margin to the good on the Revenue Account, viz. £2,089 18s. 11d., after providing £3,000 for Mortgage Redemption and Contingencies, compares favourably with £3,776 17s. 7d. in 1916.

Mortgages.—

	£	s.	d.
In the Accounts for 1916 these stood at	32,719	4	10
Amount of repayment during the year..	805	4	10
They now stand at	£31,914	0	0

Life Compositions Fund.—The total of the Fund on the 1st January, 1917, was £5,256 15s., and a further amount of £67 4s. was received in payment of Life Compositions

during the year, a total of £5,323 19s. Out of this the sum of £40 10s has been transferred to the General Fund, in accordance with the Articles of Association, on account of Life Compositions of members deceased during the year leaving to the credit of the Fund £5,283 9s.

Building Fund.—This has been augmented during the year by—

	£	s.	d.
Donations, Subscriptions, etc.	43	2	6
Contribution out of Institution Revenue .	762	2	4
	£805	4	10

which amount was applied in reduction of the Economic Life Assurance Society's mortgage as shown above.

Assets.—Taking the Tothill-street Property and the Investments at cost and the Institution Building and Lease, the Library and Furniture, etc., at the values standing in the books after writing off depreciation—

	£	s.	d.
the Assets amount to	127,897	14	1
against Liabilities	43,117	9	0
leaving a balance to the good of ..	£84,780	5	1

which is made up as follows :—

	£	s.	d.	£	s.	d.
Building Fund .. .	45,523	1	10			
Life Compositions Fund	5,283	9	0			
Kelvin Lecture Fund ..	648	13	0			
Foreign Visit Fund ..	92	14	2			
Reserve Fund	3,000	0	0			
General Fund .. .	30,232	7	1			
				84,780	5	1
This balance in comparison with that of 1916 of				78,188	14	2
shows an improvement for 1917 of .				£6,591	10	11

War Loan.

Since the accounts for 1917 were closed, a further £4,000 5 % National War Bonds has been purchased by the Institution.

Library.

In consequence of the taking over of the Institution Building by H.M. Office of Works, it has not been possible, with the exception of a small number of works of reference and bound volumes of periodicals, to transfer the Reference and Ronalds Libraries to the Institution's temporary offices, and they are therefore not accessible for the present, with the exception indicated above.

The Library and Reading Rooms of the Institution of Civil Engineers have been kindly placed at the disposal of members while the Institution is in temporary premises.

The Lending Library has been removed to the Institution's temporary offices, and continues to be available for the loan of books to members, who can obtain the same on application to the Secretary.

During the year, 354 books were issued from the Lending Library to 191 borrowers, the corresponding numbers in the previous year being 516 and 240 respectively.

Thompson Memorial Library.

The purchase of the library of the late Dr. Silvanus P. Thompson, with a view to its being presented to the Institution, will, it is expected, be completed at an early date, and the presentation will take place as soon as circumstances permit of this being done.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

REVENUE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1917.

Dr. EXPENDITURE.

Year ended 31 Dec., 1916.		£ s. d.	£ s. d.
£ s. d.			
	To MANAGEMENT :—		
	Salaries and Wages (including Staff Provident Scheme and War Bonus) ...	3,969 10 1	
	National Insurance	9 1 6	
	Accountants' Fees	42 0 0	
	Printing	246 17 6	
	Stationery and Office Requisites	202 9 1	
	Addressing Machine Plates	10 9 6	
	Postage of Correspondence and Notices	231 0 2	
	Telephone	48 14 2	
	Travelling Expenses	39 2 3	
	Bank Charges	5 17 11	
4,408 19 3			4,895 11 2
	„ INSTITUTION BUILDING :—		
	Ground Rent	2,201 0 0	
	Rates and Taxes	804 6 0	
	Light and Power	31 4 10	
	Firing...	55 14 9	
	Insurance	150 5 3	
	Reserve for Repairs	400 0 0	
	Household Requisites and Cleaning ...	27 4 11	
5,026 7 4			3,669 15 9
—	„ TEMPORARY OFFICES (No. 1 Albemarle Street) :— Rent, etc.		813 0 7
1,398 18 2	„ INTEREST ON MORTGAGES		1,364 19 9
19 10 11	„ FURNITURE AND FITTINGS (Repairs and Renewals)		49 18 6
	„ JOURNAL :—		
	Printing	1,300 11 10	
	Postage	415 17 0	
	Wrappers and Envelopes	43 8 0	
		1,759 16 10	
	Less Sales	391 19 4	
1,405 12 10			1,367 17 6
16 13 10	„ LENDING LIBRARY (Books, Printing, Postage, etc.) ...		27 16 4
—	„ THOMPSON MEMORIAL LIBRARY :— Removal of Books, Insurance, etc.		22 2 10
	Carried Forward		£12,121 2 5

Cr. INCOME.

Year ended 31 Dec., 1916.		£ s. d.	£ s. d.
£ s. d.			
14,986 15 3	By SUBSCRIPTIONS		... 15,399 18 0
467 5 0	„ ENTRANCE FEES		583 5 6
16 16 0	„ LIFE COMPOSITIONS		67 4 0
	„ BUILDING FUND :—		
	Donations and Subscriptions	11 12 6	
	Vellum Diplomas	31 10 0	
44 15 8			43 2 6
381 1 1	„ DIVIDENDS ON INVESTMENTS		620 1 11
168 1 6	„ INTEREST...		142 18 3
22 19 9	„ WIRING RULES...		7 14 5
9 16 3	„ MODEL GENERAL CONDITIONS		19 5 3
	„ INSTITUTION BUILDING :—		
2,726 2 6	Rent from Tenants		5,086 4 5
	„ TOTHILL STREET PROPERTY :—		
	Rents from Tenants	851 8 4	
	Less Ground Rent, Repairs, Alterations, Rates, Taxes, etc.	376 5 7	
527 12 9			475 2 9
	Carried Forward		... £22,444 17 0

Dr.	EXPENDITURE—*continued.*	£ s. d.	£ s. d.
	Brought Forward	...	... 12,121 2 5
	To NATIONAL SERVICE :—		
	Honours Lists, Greetings Card, Postage, etc.	27 14 11	
	Allowances to Members of Staff on Military Service	580 5 8	
445 14 10			608 0 7
	„ SCIENCE ABSTRACTS :—		
	Salaries, Abstracting, Printing, Postage, etc.	2,059 14 2	
	Less Subscriptions, Sales, and Advertisements	1,546 4 11	
291 10 3			513 9 3
	„ MEETINGS :—		
	Advance Proofs	41 9 2	
	Reporting	48 6 0	
	Refreshments, Assistance, etc.	65 12 0	
	Hire of Rooms	42 0 0	
201 5 9			197 7 2
	„ LOCAL SECTIONS :—		
	Money Grants	552 7 5	
	Travelling Expenses	202 1 5	
763 14 5			754 8 10
72 9 9	„ PREMIUMS	... ...	50 17 9
25 0 0	„ ENGINEERING STANDARDS COMMITTEE ...	... ...	550 0 0
	„ CONJOINT BOARD OF SCIENTIFIC SOCIETIES	... ...	50 0 0
	„ SHIP WIRING RULES (Preliminary expenses)	... ...	3 14 6
	„ RESEARCH :—		
	Buried Cables and Insulating Oils ...	53 1 10	
	Electrical Research Committee	100 0 0	
203 0 4			153 1 10
46 14 4	„ LEGAL EXPENSES	... ...	62 10 0
56 14 9	„ MISCELLANEOUS EXPENSES	... ...	78 13 8
	„ AMOUNTS TRANSFERRED TO :—		15,143 15 0
16 16 0	LIFE COMPOSITIONS FUND (*per contra*) ...	67 4 0	
	BUILDING FUND (Obligatory repayment to Economic Life Assurance Society) :—		
	Donations, Subscriptions, etc. (*per contra*) ... £43 2 6		
	Contribution out of Revenue 762 2 4		
772 0 6		805 4 10	
	SINKING FUND (Premiums for Redemption		
277 12 2	of Cost of Building and Lease) ...	277 12 2	
	RESERVE FUND (Mortgage Redemption and Contingencies)	3,000 0 0	
	GENERAL FUND :—		
	Expenditure on—		
72 15 4	Books and Binding for Library ...	57 17 1	
25 0 0	Furniture	3 5 0	
	Thompson Memorial Library (Contribution towards purchase)	1,000 0 0	
3,776 17 7	**Balance of Revenue for the year 1917**	2,089 18 11	
			7,301 2 0
			£22,444 17 0

INCOME—*continued.*	£ s. d.	Cr.
Brought Forward	... 22,444 17 0	
	£22,444 17 0	

BALANCE SHEET, 31ST DECEMBER, 1917.

Dr. LIABILITIES. ASSETS. **Cr.**

	£ s. d.	£ s. d.
To BUILDING FUND :—		
Balance at 1st January, 1917	44,717 17 0	
Donations, Subscriptions, etc.	43 2 6	
Contribution out of Revenue	762 2 4	
		45,523 1 10
„ ECONOMIC LIFE ASSURANCE SOCIETY :—		
On Mortgage of Institution Building (1909) ...	26,000 0 0	
Since repaid	5,586 0 0	
	20,414 0 0	
On Mortgage of Tothill Street Buildings and Site (1910)	11,500 0 0	
		31,914 0 0
„ LIFE COMPOSITIONS FUND :—		
Balance at 1st January, 1917	5,250 15 0	
Life Compositions received in 1917	67 4 0	
	5,323 19 0	
Less Life Compositions of Deceased Members transferred to General Fund	40 10 0	
		5,283 9 0
„ KELVIN LECTURE FUND :—		
As per last Balance Sheet		648 13 0
„ TRUST FUNDS CAPITAL ACCOUNTS :—		
Salomons Scholarship	2,120 19 3	
David Hughes Scholarship	2,000 0 0	
Wilde Benevolent Fund	1,840 4 6	
		5,973 3 9
„ TRUST FUNDS INCOME ACCOUNTS :—		
Balances unexpended :—		
Salomons Scholarship	148 0 9	
David Hughes Scholarship	196 13 3	
Wilde Benevolent Fund	43 0 8	
	387 14 8	
Invested Income (Wilde Benevolent Fund)	540 14 8	
„ FOREIGN VISIT FUND	02 14 2	
„ SUNDRY CREDITORS	3,732 5 4	
„ SUBSCRIPTIONS RECEIVED IN ADVANCE	172 16 9	
Carried Forward	94,268 13 2	

	£ s. d.	£ s. d.
By INSTITUTION BUILDING AND LEASE :—		
Cost	73,028 6 10	
Less Reserve for Depreciation, being Sinking Fund Premiums paid	2,404 4 0	
		70,624 2 10
„ SINKING FUND (Premiums paid for Redemption of Cost of Building and Lease)		2,404 4 0
„ TOTHILL STREET BUILDINGS AND SITE (at cost)		19,260 17 1
„ LIFE COMPOSITIONS INVESTMENTS (at cost)* :—		
£2,600 Natal Zululand Railways 3 % Debentures	2,270 12 0	
£1,500 Lancashire and Yorkshire Railway 4 % Preference Stock	1,513 10 4	
£2,000 Assam Bengal Railways 3 % Stock ...	1,548 0 6	
		5,332 2 10
„ KELVIN LECTURE FUND INVESTMENT (at cost)* :—		
£694 16s. 9d. 5 % War Stock		648 13 0
„ TRUST FUNDS INVESTMENTS (at cost)* :—		
Salomons Scholarship :—		
£1,500 New South Wales 3½ % Stock	1,550 5 9	
£500 Cape of Good Hope 3½ % Stock	570 13 6	
	2,120 19 3	
David Hughes Scholarship :—		
£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998 15 0	
Cash at Post Office Savings Bank	1 5 0	
	2,000 0 0	
Wilde Benevolent Fund (Capital Account) :—		
£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493 16 3	
£215 North Eastern Railway 4 % Guaranteed Stock	250 19 9	
£100 London County 3½ % Stock	101 8 6	
	1,846 4 6	
Wilde Benevolent Fund (Income Account) :—		
£250 New South Wales 4 % Stock	251 6 0	
£100 3½ % War Stock	94 8 8	
£100 5 % War Stock	95 0 0	
£100 5 % National War Bonds	100 0 0	
	540 14 8	
„ LIBRARY (exclusive of the Ronalds Library and Faraday Papers, which are held in trust) :—		
As per last Balance Sheet	1,258 14 1	
Additions in 1917	57 17 1	
	1,316 11 2	
Less Depreciation (10 %)	131 13 1	
		1,184 18 1
Carried Forward		105,068 16 3

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.*

	£ s. d.	£ s. d.
Brought Forward		94,268 13 2
To REPAIRS SUSPENSE ACCOUNT :—		
Balance (as per last Balance Sheet)	285 15 11	
Amount set aside in 1917	400 0 0	
	685 15 11	
Less Expenditure on Repairs in 1917... ...	289 2 1	
		396 13 10
„ RESERVE FUND (Mortgage Redemption and Contingencies) ...		3,000 0 0
„ GENERAL FUND :—		
Balance at 1st January, 1917	27,290 12 7	
Life Compositions of Deceased Members ...	40 10 0	
Expenditure in 1917 on—		
Books and Binding for Library	57 17 1	
Furniture	3 5 0	
Thompson Memorial Library (Contribution towards purchase)	1,000 0 0	
Balance of Revenue for 1917	2,089 18 11	
	30,482 3 7	
Less Depreciation (*per contra*) :—		
Library £131 13 1		
Furniture, Fittings, and Apparatus 118 3 5		
	249 16 6	
		30,232 7 1
		£127,897 14 1

J. E. KINGSBURY,
Honorary Treasurer.
P. F. ROWELL,
Secretary.

Cr. ASSETS—*continued.*

	£ s. d.	£ s. d.
Brought Forward		105,968 16 3
By THOMPSON MEMORIAL LIBRARY (Contribution towards purchase)		1,000 0 0
„ FURNITURE, FITTINGS, AND APPARATUS :—		
As per last Balance Sheet	2,300 3 6	
Additions in 1917	3 5 0	
	2,303 8 6	
Less Depreciation (5 %)	118 3 5	
		2,245 5 1
„ SUNDRY DEBTORS		3,535 1 4
„ INSURANCE PREMIUMS AND SUNDRY PAYMENTS IN ADVANCE ...		197 18 8
„ STOCK OF PAPER FOR PUBLICATIONS		794 8 2
„ GENERAL AND RESERVE FUNDS INVESTMENTS (at cost)* :—		
£750 Western Australia 4 % Stock	730 8 3	
£750 Union of South Africa 4 % Stock	742 12 0	
£750 Madras and Southern Mahratta Railway 4 % Debenture Stock	738 18 6	
£35 East Indian Railway "B" Annuity	791 5 4	
£1,500 South Australian 4% Stock	1,494 10 6	
£5,250 5 % War Stock	4,987 10 0	
£4,000 5 % National War Bonds	4,000 0 0	
		13,485 1 7
„ CASH :—		
At Bankers'	655 0 9	
At Post Office Savings Bank (David Hughes Scholarship Trust Fund Uninvested Income)	0 1 3	
In hands of Secretary...	16 1 0	
		671 3 0
		£127,897 14 1

* The above values are subject to depreciation, but, in view of the continuance of the War, no estimate of present values can usefully be made.

We beg to report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1917, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct, and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of the Institution.

SIDNEY SHARP, *Honorary Auditor.*

ALLEN, ATTFIELD & CO., *Auditors,*
Chartered Accountants,
147, LEADENHALL STREET, E.C. 3.

15th April, 1918.

SALOMONS SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Balance carried to Balance Sheet	148 0 9	By Balance (as per last Account)	78 18 3
		„ Dividends received in 1917	69 2 6
	£148 0 9		£148 0 9

DAVID HUGHES SCHOLARSHIP TRUST FUND (Income).

Dr.	£ s. d.	Cr.	£ s. d.
To Balance carried to Balance Sheet	196 13 3	By Balance (as per last Account)	137 10 4
		„ Dividends received in 1917	59 2 5
		„ Interest do. do.	0 0 6
	£196 13 3		£196 13 3

WILDE BENEVOLENT TRUST FUND (Income).

Dr.	£ s. d.	£ s. d.	Cr.	£ s. d.
To Amount invested during 1917 :—			By Balance (as per last Account)	100 15 2
£100 5% War Stock	95 0 0		„ Dividends received in 1917	72 17 11
£100 5% National War Bonds	100 0 0		„ Interest do. do.	4 7 7
		195 0 0		
„ Balance carried to Balance Sheet		43 0 8		
		£238 0 8		£238 0 8

RESEARCH ACCOUNT (1917)

Dr.	£ s. d.	Cr.	£ s. d.
To Expenditure on Research on Buried Cables	324 3 5	By Grants from Department for Scientific and Industrial Research	757 10 0
„ Expenditure on Research on Insulating Oils	467 3 2	„ Grant from Institution	53 1 10
„ Balance carried forward	322 10 3	„ Contributions from Electricity Supply Undertakings	296 7 0
		„ Interest	6 18 0
	£1,113 16 10		£1,113 16 10

THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1917.

Dr. Expenditure.	£ s. d.	Income.	£ s. d.	Cr.
To Grants	197 15 0	By Dividends on Investments	228 19 4	
„ Printing, Stationery, and Postage	2 15 9	„ Interest	6 17 9	
„ Unexpended Balance carried to Balance Sheet	229 8 4	„ Annual Subscriptions	113 10 6	
		„ Donations of £5 and over	56 5 0	
		„ Donations under £5	24 6 6	
	£429 19 1		£429 19 1	

BALANCE SHEET, 31ST DECEMBER, 1917.

Dr. Liabilities.	£ s. d.	£ s. d.	Assets.	£ s. d.	£ s. d.	Cr.
To Capital (as per last Balance Sheet)	4,642 3 0		By Investments (Capital), at cost :—			
„ Income and Expenditure Account :—			£961 7s. 7d. Cape of Good Hope 3 % Stock		950 0 0	
As per last Balance Sheet	£1,833 3 10		£593 1s. 7d. New South Wales 3 % Stock		600 0 0	
Unexpended Balance in 1917	229 8 4		£420 Great Eastern Railway 4 % Preference Stock		503 18 3	
	2,062 12 2		£600 North Staffordshire Railway 3 % Debenture Stock		551 0 9	
„ Sundry Creditors	18 19 10		£750 East Indian Railway 3½ % Debenture Stock		737 18 0	
			£300 London and North-Western Railway 4 % Guaranteed Stock		333 11 6	
			£500 New Zealand 3½ % Stock		486 18 6	
			£500 Canada 3½ % Stock		478 16 0	
				4,642 3 0		
			„ Investments (Income), at cost :—			
			£350 New South Wales 4 % Stock	£336 18 6		
			£200 3½ % War Stock	188 17 3		
			£1,126 6s. 3d. 5 % War Stock	1,067 6 6		
			£100 5 % National War Bonds	100 0 0		
					1,693 2 3	
			„ Sundry Debtors		180 0 0	
			„ Cash :—			
			At Bankers'	£182 0 5		
			In hand	26 9 4		
					208 9 9	
	£6,723 15 0				£6,723 15 0	

We have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Bankers. The Investments, which are stated at cost, are subject to depreciation.

30th April, 1918.

JAS. ATTFIELD, F.C.A.
SIDNEY SHARP, } *Honorary Auditors.*

DISCUSSION ON

"ELECTRICAL SIGNALLING AND CONTROL ON RAILWAYS." *

Scottish Local Section, 12 March, 1918.

Mr. R. Boath: The Great Western Railway have the credit of being the first to avail themselves of electrical methods of working. This was between Paddington and West Drayton in 1839, and it is generally admitted that this was the inception of electric block signalling. The author has given a comparison between the British and American signal aspects, in favour of the latter. It should be kept in mind that the American three indications given by a single arm require electric or electro-pneumatic power, and that this can only be considered where the power can be economically obtained locally or if the installation is large enough to warrant a separate plant. Our British signal aspects have stood the test of time and criticism very well up till now. There may, however, be some special places on our railways where the three indications might be useful. With regard to automatic train control, the author says "the subject is a very controversial one" and I am sure his words are coming true. Whenever a railway accident occurs through the failure of a man, either driver or signalman, there is an outcry for the adoption of automatic devices, and it is at such times that the railway officers require to draw on their technical experiences to consider judiciously the various suggestions that are bound to be made, and of course to look to their company's interests with regard to their obligations both to the travelling public and to the shareholders. The question of automatic train control is older than many realize, and has long passed the experimental stage. In our Colonies, in America, and on the Continent there are hundreds of miles installed. The author says that in the Great Western system the disposition of the shoe and ramp, in the centre of the running rails, is most practical and convenient. I am afraid that if some companies were to adopt this system the ramp would not have to be fixed in the centre of the running rails, as it might get damaged by loose couplings hanging from passing wagons. I see no practical difficulty, however, in the ramp and shoe being fixed so as to obviate this. I am not yet satisfied that any automatic train control has been proved to be thoroughly reliable during severe frost and snow. I know that great difficulty has been found in America. I believe that the Great Western Railway tried to get over this by steam heating the apparatus. It may be of interest to mention that the North British Railway on the new Lothian goods lines at Portobello have a non-token system which has been installed for about two years. No staff or tablet is employed and yet all the security claimed for the latter method of working is given. The author is, I think, wise in calling attention to the fact that no electrical system can be absolutely safe or absolutely fool-proof, and that it cannot even yet eliminate the human element, because it has to be looked after by a human being. When any railway officer is considering the advisability of adopting an electrical or mechanical appliance, he has many tough problems to deal with. Of course for economy's sake we should, if at all possible, like to standardize the signalling and control of railways, but although we have progressed so far, I am afraid this desirable aim is not yet within our reach. The present war has probably given the question a set-back; but as there are so many electrical and mechanical devices being developed and perfected in connection with the war it is not improbable that some of them may yet be adopted to improve still further the appliances we have to select from. Another point I would call attention to is that the driver's side on the engine is the left-hand side on some companies' engines and the right-hand side on others. Personally I think that the left-hand side is the correct and natural side for a driver, as the signals and platforms are mostly on his left hand. It will therefore be seen that there has always been great difficulty with regard to the whole question, and it will be difficult to arrive at any uniformity or standardization of practice between the various companies. It may be that if, after the war, the railways are nationalized we shall be in a better position to arrive at some standardization of electrical signalling and control of railways.

Mr. J. R. Shewan: There is only one section of the paper on which I should like to pass a few remarks, viz. track circuiting. In my opinion the author has brought forward the very important fact that the track circuit, as we know it to-day, is quite unreliable under certain conditions, for example, with rusty or heavily sanded rails. He suggests a system of classification of tracks, but on this point I cannot say I agree, for the simple reason that the shunt value of a complete train can, under certain conditions of the track, be as poor as that of a single vehicle. The next suggestion is the use of high-voltage track circuits. While I quite agree that such a system would give the necessary low shunt working, it is quite apparent that to get the low shunt working we must state a minimum insulation resistance, and maintain it; therefore I am of the opinion that the initial and maintenance costs for such a track would be so heavy as to prohibit its use. The average track circuit would require to be split into four or five sections to get a minimum insulation of 20 ohms per section. This would mean four or five 18-volt batteries and four or five relays. In conclusion, I suggest that a new system be tried having a relay wound with a series and shunt winding,

* Paper by Mr. C. M. Jacobs (see pages 136 and 169).

the windings, when connected up, being magnetically in opposition to each other. The shunt winding could be connected across the battery terminals, whilst the series winding would be connected to the track circuit, hence all the current flowing in the series winding would pass through the insulation resistance. While the track circuit would be normal, the shunt winding ampere-turns would overcome the series ampere-turns, and being a polarized relay the armature would be held over to the locking control side. When a train comes on the track, the series current would be increased, and hence an increase would take place in the series ampere-turns, but not in the shunt ampere-turns; therefore the series would overcome the shunt and hold the relay over to the opposite side from locking control, thereby locking the levers, etc.

Mr. D. S. Munro: The methods described by the author, even with suggested improvement in the proportions of the actuating currents, seem far too sensitive to be safely dependent upon the very fluctuating resistance of the ballast. That they have had so great a measure of success is much to the credit of the instrument makers and of those who have had charge of their operation. Direct-current devices involve the use of solenoids, make-and-break arrangements with their springs, contacts, and set screws, and worst of all they necessitate small batteries. In addition to these disadvantages a direct-current circuit always encourages leakage and corrosion. Reliable main-line signalling apparatus should be standardized in a form applicable to considerable distances, and in a manner guarded from fall of pressure faults, or on the other hand from leakage currents from neighbouring power lines. It would seem that the inductive alternating magneto, which has proved so reliable for long-distance telephones, could be applied hopefully to block signalling work. With a magneto in the cabin and with polarized coils and a rocking armature at the signal post, every rotation of the magneto is positively accompanied by a certain definite series of movements of the rocking armature. These regulated vibrations of the armature might easily be adapted to operate a ratchet escapement. The escapement through a simple mechanical relay could be applied to semaphore posts, lamps, or cab indicators. A few rotations of the armature would release the escapement till the signals stood at "clear." Twice the number of motions would indicate "caution," and thrice would signal "stop." It would not be difficult to arrange a special prolonged emergency stop signal which could apply the train-lighting battery to a magnetic valve on the vacuum brake. It is admitted that an audible signal in the cab is desirable, and here the magneto bell would probably work with greater certainty than a direct-current arrangement. In a main-line signal box the separate magneto generators should be power-operated with push buttons to control the generator revolutions, while a more simple hand arrangement might serve for unimportant lines. The alternating-current circuit tends to remove moisture leakage automatically, and this is specially important under exposed railway conditions; then by fitting condensers one may confine the effects of possible damage by leakage from a local power circuit. Track-circuiting conditions will change when rails are bonded, and perhaps cross bonded, for earth return for electric traction. It may then be necessary to fit a high-resistance centre-rail contact circuit on the first and last pair of wheels of every train with or without an automatic interruption device in tune with the relative alarm signal in the cabin and on the locomotive. Even on existing steam lines a track circuit should show when there is no leakage current from rail to rail, i.e. it should indicate a broken circuit. Mr. Thorrowgood has referred (see page 145) to the white light signals on the Chicago and Milwaukee Railway. He did not make it clear whether these were carried on moving arms to accentuate the position or whether the electric lamps are fixed and lit in varying groups, vertical, horizontal and so on. The latter method gets rid of all outdoor moving parts if only the white lamps with their reflectors and shades are clearly visible and distinctive in bright sunlight.

Mr. E. Seddon: I have no practical experience of railway signalling but there is one point which occurred to me when reading the paper. I should like to ask the author whether signalling direct to the locomotive has been tried by running over an insulated track which could be supplied by two or three different voltages to operate the necessary number of signals. The cab would require relays and lamps to show the various signals.

Mr. C. E. Cockburn also took part in the discussion. In the course of his remarks he stated that he had come prepared to listen, and although not prepared to address them on the subject he gave his views in connection with orange lights and lock and block. He thought that the use of an orange light for cautioning purposes was a mistake, and to overcome the necessity of such a method he thought it would be a great deal better to make use of banner signals as "calling-on" signals, the banner signals to be placed under the running signals, where the necessity for such arose, and he was of opinion that this method was being introduced on the London, Brighton & South Coast and other railways as well as on his own, where it was found to work quite successfully. He also gave the meeting the benefit of his experience in connection with single line working by means of an electrical control of the signals in lieu of the use of a tablet or staff, and said that the controlling of the signals had proved an efficient means of working a single line. With regard to the question of giving drivers freedom in connection with the introduction of train control on engines, he stated that in his opinion this led up to the same position as had been experienced in connection with Sykes's lock and block where in the first instance the control had been absolute, but in order to meet the necessities of train working it had been made to give more or less freedom by the use of a releasing key. He, therefore, thought that the train control system should not be condemned because it had to fall back on the human element in connection with this working any more than lock and block should not be condemned for requiring the same freedom, and he requested his hearers not to condemn one or

other simply because the human element at times may fail.

Mr. A. S. Hampton (*communicated*): Railway signalling is not as complicated as it appears from the paper, and the tendency is undoubtedly towards simplicity. Electrical appliances added to the existing mechanical signalling apparatus have increased the load factor and the safety of railway working. Track circuits have been found more reliable, and much more study will have to be given to this important problem before a change is made from the 4·5- and 9-ohm relays to those of higher resistance, as suggested by the author. Two-volt track batteries with ordinary ballast are not difficult to maintain, and if the author's suggestion to increase the electromotive force is adopted, a much improved ballast resistance will have to be secured to make maintenance anything like as easy as it is at present. The engineering departments do everything they possibly can to keep the ballast clean and well drained, and it is difficult to say how improvement could be obtained. When rails are clean, a single vehicle will usually short-circuit the track, and unreliability with a single vehicle is only experienced at the ends of track-circuited docks, and in such cases the controlled interlocking can be made perfectly safe by fixing one or more balanced bars to one of the rails. Balanced bars have certain disadvantages on main lines where trains are always running at high speeds, but in dock lines where the speed is always low, they can be used with absolute safety. There is no doubt that track-circuiting practice on different railways is not uniform, and if the suggestions and data put forward by the author are carefully studied, and a standardized system adopted for the three classes of track circuits mentioned on page 137, a great improvement would be effected. Automatic train control has of late been frequently recommended as a means of preventing accidents which have occurred at points where signals are in positions which are at times and under certain climatic conditions difficult to see. The system described by the author has its limitations, inasmuch as it only takes cognizance of the "distant" signal, which is not a stop signal; indeed it is assumed that this is the only signal likely to be passed or misread by the driver. The repetition of all the "stop" as well as "distant" signals would seriously complicate this system. A close study of the Blue Book on Railway Accidents proves that the "distant" signal is not the only one passed or misread. On the other hand, few responsible traffic officers will admit that it would be a good principle to repeat all the outdoor signals in the cab of the locomotive, as the first duty of the driver is to keep a good look-out, not only for signals, but for other obstructions that may be on the road. The more general opinion seems to be that, while at all times leaving the control of the brake in the hands of the driver, the brake should be automatically applied only at "stop" signals. The ideal system would be an arrangement which would make it impossible for the driver to take the brake off after being automatically applied at a stop signal until the train has come to a stand; and it is a question whether the author's system could be arranged to meet all the grades of roads, single and double line working, different types of locomotives, locomotives running tender first, etc. The system which he describes is mostly electrical, yet there is another system wholly mechanical of which no mention is made. In this latter system there is no repetition of signals, but the brake can be automatically applied at every signal by means of a very simple arrangement worked in conjunction with the signals. This mechanical system is by no means ideal, but it certainly seems capable of being very much improved, and there is no doubt that when the call for automatic control becomes more general, railway engineers will design a system which will satisfy all the conditions.

Staff-Sergeant L. M. Jockel, R.E. (*communicated*): A rather important point in railway-signalling practice is the illumination of the signals themselves, and in many cases this is efficiently carried out by electric lamps. The advantages of electrically lighted signals are of course obvious, and provided that very careful consideration is given to the installation and efficient tell-tale indicator devices are employed, the system will generally prove satisfactory even on main steam lines, as distinct from electrified or underground systems, where the conditions are perhaps not so severe. The importance of sound installation work and suitable materials cannot be over-estimated. A rather important case of signal lighting on the main line of one of our largest railway systems came under my notice just prior to the outbreak of war. The supply of energy for the lighting of the section was obtained direct from the local supply authority at a pressure of 220 volts continuous current, and distributed from the adjacent passenger station to the various signal cabins. Unfortunately the supply pressure was very variable when the supply station was dealing with the evening load, and a great deal of trouble was experienced with the failure of the lamps on the signal circuits. Further, trouble was experienced with the distribution system at times, owing to breakdowns of insulation and electrolysis, etc., the wiring having been carried out with ordinary cables of first-class manufacture in screwed iron piping, which in several places was laid underground for additional mechanical protection. The latter troubles were eventually overcome, however, by the employment of "cab tyre" cables and the alteration of a considerable portion of the pipework to prevent troubles from condensation and any ingress of storm water, etc., on the more exposed parts of the distribution system. Vibration troubles were also experienced on some of the sections, the train vibrations being severely felt on certain of the steel lattice-work signal posts. The author unfortunately mentions very little in the paper about the importance of the supply of electrical energy for signal purposes, but perhaps this is attributable to the fact that most railway companies depend so largely upon primary batteries at present, and the advantages of electricity for the auxiliary services of the present steam lines are as yet not sufficiently appreciated. If continuous current is employed for signal and other auxiliary services on the permanent way, reliability should be a primary factor, and it would seem inadvisable to employ pressures exceeding, say, 150 to 200 volts owing to the

liability of insulation or electrolysis troubles, which are prevalent in this climate even with very moderate pressures. In many instances an efficient supply of energy is available from the adjacent high-tension distribution system of a power company, and a cheap and reliable supply can be obtained at suitably situated substations on the various sections of the line. A portion of the supply can then be converted to continuous current at low pressure for signal-lighting purposes, in connection with storage batteries for standby and pressure regulation purposes, and alternating current at any desired pressure used for signal operating and other auxiliary railway services. No doubt alternating current at low or moderate pressures possesses certain advantages over continuous current for the latter operations, and reliability is undoubtedly of paramount importance in railway operation. Experience with continuous current at medium pressures for signalling, point-operating, and other auxiliary services on electric tramway systems has inclined me to the belief that unless considerable improvements can be made in the design of the apparatus employed at present, alternating current is certainly more reliable under severe service conditions in this climate.

Mr. C. M. Jacobs (*communicated reply*) : The banner signals mentioned by Mr. Cockburn are no doubt very suitable for terminal stations, but a light signal seems necessary for high-speed lines. If the only objection to an orange light is that it may sometimes be mistaken for a white one, and if a white light is treated as a " stop " indication, the mistake is on the right side.

While our British signalling aspects, as Mr. Boath says, have very well stood the test of time, they are insufficient, in that at night the " stop " and " proceed with caution " indications are the same. The adoption of the three-phase signal would, moreover, tend to the simplification of the present somewhat complicated block telegraph rules and regulations governing the signalling of trains in short sections.

Mr. Shewan's suggestion for a track-circuit relay is well worth consideration, although at first sight I should say it is doubtful if it would result in an improved shunt. Some such method might be useful if it were required, as suggested by Mr. Munro, to detect broken rails.

Mr. Munro's suggestion for operating the three fundamental signal indications is scarcely good signalling. It is essential that the " stop " indication should be exhibited when there is no current passing.

The arrangement Mr. Seddon inquires about is hardly practicable, as if from any cause there should be an unintentional drop in voltage, a different signal from that intended might be indicated on the locomotive.

I gather Mr. Hampton agrees that a case has been made out for standardizing track circuits. That seems to be the general view, and one object of the paper would appear to have been attained.

Further, although, as Staff-Sergeant Jockel remarks, little is said in the paper on the subject, the discussion on the paper generally has emphasized the importance of a supply of electrical energy for signalling purposes.

PROCEEDINGS OF THE INSTITUTION.

607TH ORDINARY MEETING, 21 FEBRUARY, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 7th February, 1918, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors :—

Benevolent Fund : G. Allom, S. Beeton, I. Braby, J. Burns, R. A. Chattock, H. C. Channon, F. W. Clements, W. C. Clinton, W. W. Cook, The Hon. E. H. Cozens-Hardy, I. S. Dalgleish, B. Davies, F. E. Davies, F. R. Davenport, Sir A. Denny, Bart., J. Devonshire, B. M. Drake, Dr. C. V. Drysdale, Major K. W. Edgcumbe, R.E., E. Garcke, F. Gill, Sir Richard Glazebrook, C.B., F.R.S., G. F. C. Gordon, F. E. Gripper, C. W. Gwyther, H. T. Harrison, C. C. Hawkins, W. C. C. Hawtayne, Killingworth Hedges, J. S. Highfield, H. C. Holroyd, The Institution of Railway Signal Engineers, E. S. Jacob, Dr. G. Kapp, Major A. C. Kelly, R.E., W. T. Kerr, W. E. Lane, A. E. Levin, Sir Henry Mance, C.I.E., E. Manville, J. W. Meares, S. W. Melsom, C. H. Merz, L. B. Miller, W. M. Mordey, Colonel A. M. J. Ogilvie, C.B., R.E., C. Oliver, The Hon. Sir C. A. Parsons, K.C.B., F.R.S., W. H. Patchell, F. G. Payne, A. H. Preece, W. L. Preece, N. Prentice, H. F. Proctor, H. A. Ratcliff, R. Robertson, T. Rich, S. R. Roget, S. A. Russell, S. G. C. Russell, C. Stewart, A. Siemens, H. A. Skelton, Sir John Snell, A. J. Stubbs, H. W.

Sullivan, E. E. Tasker, Captain C. H. R. Thorn, A. P. Trotter, W. B. Woodhouse, J. H. Woodward, and H. E. Yerbury.

Building Fund: J. S. Highfield, H. Hirst, W. M. Mordey, Sir John Snell, and H. W. Young.

Library: U.S.A. Bureau of Mines, T. Carter, R. de Valbreuze, The Department of Communications (Tokyo), The Engineering Standards Committee, A. Fell, Sir Francis Fox, Sir Robert Hadfield, Bart., R. P. Howgrave-Graham, The Imperial Institute, The Meteorological Committee, The Munitions Inventions Department, Sir George Newman, The Legislative Assembly of Ontario, H. S. Russell, The Smithsonian Institute, A. A. C. Swinton, H. G. Taylor, L. H. Walter, and The Wireless Press, Ltd.

A paper by Dr. C. C. Garrard, Member, entitled "Switchgear Standardization" (see page 213), was read and discussed, and the meeting adjourned at 7.45 p.m.

608TH ORDINARY MEETING, 7 MARCH, 1918

Held in the rooms of the Institution of Civil Engineers

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 21st February, 1918, were taken as read, and were confirmed and signed.

Messrs. W. C. Clinton and B. B. Heaviside were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

Carr, Lancelot Stobart. Walker, Henry.

Associate Members.

Ayres, William Edward Milton.
Beecroft, Samuel Ernest Roland.
Belfield, Stafford St. Geo. C.
Bust, Frederick Hodgetts.
Clark, William Edward.
Clay, Robert Carpenter.
Cook, Ernest.
Cox, Leslie Charles.
Dancer, William.
Forsyth, Reginald Douglas.
Green, Edmund Caspall.
Hole, William Albert.
Hyde-Thomson, Douglas Hyde, Lt. R.N.
Kennedy, Oliver Henry.
Long, Sidney Herbert.
McMonan, David.
Moir, Albert Thomas King.
Newsome, George A.
Nias, Carl.
Norie, James Ross Davis.
Owen, Charles Maxwell.
Owen, William Davies.
Parrott, Ernest George.
Poole, Gordon George Thomas.
Ripley, Henry Percy.
Sloan, Norman Ernest Woods.
Spark, Thompson Douglass.
Thurman, Albert Thomas.
Walter, Cecil Montague.
White, Tom M'Call.
Willis, Arnold Morley.
Wilson, George Nicholson.

Associates.

Gresley, Herbert Nigel.
Hobbs, William Edward.
Sear, Abraham James.
Skerrett, Henry Norton.

Graduates.

Craig, John David.
Leese, William Lionel.
Minton, William John.
Prothero, Edwin George.
Rogers, Daniel Herbert.

Students.

Barfield, Turland John
Bell, Edwin Gabriel
Cook, Philip Herbert
Cope, Evan Leslie Noble
Couch, William Charles Milford.
Cox, Harold Ernest
Eatwell, Henry Thomas
Griffiths, Albert Edwin Fisher.
Hillard, Reginald Percival.
Mitchell, Arthur Patrick.
Painton, Claude Arthur.
Peacock, John Vernon.
Scarf, Charles Tate.
Sharpley, Forbes Wilmot.
Shepherd, James Ernest.
Summers, Laurence.
Vicario, Victor Charles.
Whittick, Robert Baker.

TRANSFERS.

Associate Member to Member

Beard, James Robert, M.Sc.
Driver, James Frederick
Kerr, Thomas Archibald.
Williams, Hugh Lawrance, B.A.

Associate to Associate Member

Livesey, Arthur Cecil.

Graduate to Associate Member

Bluett, Eric James Hamilton.
Elliott, Frederic James.
Livesley, Robert Edwin, B.Sc.
Rickwood, Harold Archibald.
Rowan, David.
Saunders, Charles Wallace.
Ward, Henry John.

Student to Associate Member.

Coursey, Philip Ray, B.Sc.
Peattie, John Davidson.
Perry, John Francis.

Student to Graduate.

Cripps, Cyril Burton
Gibson, Francis Barker.
Kerr, Philip Cameron
Krasemann, Herbert Anthony.
Manlove, Cecil William Walton.
Wouldham, Arthur William Petitt.

A paper by Mr. E. B. Wedmore, Member, entitled "The Control of Large Amounts of Power" (see page 269) was read and discussed, and the meeting adjourned at 7.35 p.m.

THE JOURNAL OF
The Institution of Electrical Engineers

Vol. 56. JUNE, 1918. No. 275.

DIATHERMY: THE USE OF THE ELECTRICAL CURRENT TO RAISE THE TEMPERATURE OF THE BODY IN THE TREATMENT OF DISEASE.

By E. P. Cumberbatch, B.M., M.R.C.P., M.A. (Oxon),
MEDICAL OFFICER IN CHARGE, ELECTRICAL DEPARTMENT, ST. BARTHOLOMEW'S HOSPITAL.

(*Paper received 27 March, 1918, and read at a Joint Meeting of* The Institution *and the* Electrical Section of the Royal Society of Medicine, 11 *April*, 1918.)

Heat is a valuable therapeutic agent and it has been used in the treatment of disease for centuries. In all the various methods that have been employed for the application of heat to the body, some object heated to a higher temperature than that of the body is placed either in direct contact with the skin (as, for example, a hot fomentation or hot iron) or at some distance from it (e.g. an electric lamp). In the first case the heat is imparted by conduction, in the second case by radiation.

In the most recent method heat is applied through the agency of an electric current (of special kind). When the current is passed through the body, part of the electrical energy is converted into heat as it overcomes the resistance of the tissues. There is therefore a rise of temperature of the parts traversed by the current. This method of applying heat to the body differs from all others in that it causes a rise in temperature of the deep-lying tissues as well as of those on the surface. Not only is the skin heated but also the underlying bones, muscles, and other parts. All other methods of applying heat raise the temperature of the skin only, because the latter is a very bad conductor of heat. The skin and underlying tissues can, however, conduct the electric current, although their resistance, especially that of the skin, is high. Consequently, when a current traverses the body, heat will be developed along its path; and if the current is sufficiently strong the heat can be felt by the subject and measured by a thermometer. The raising of the temperature of the tissues can modify their physiological processes, and exercise a therapeutic influence over them in cases of disease. Further, it is possible by means of the electrical current to raise their temperature to a degree sufficient to coagulate them and so destroy their vitality. The name "diathermy" signifies the "through and through" heating which the electrical current brings about, in contrast with the "surface" heating or "epithermy" produced by other methods.

The current used for diathermy.—It is well known that the electric current possesses the power to stimulate the tissues of the body, especially the excitable tissues, viz. muscle and nerve. The disagreeable and painful sensation evoked by the stimulation of these tissues makes it quite impossible to increase the strength of the current (or, more correctly, the density of the current) sufficiently to heat the parts of the body through which the current flows. If the direct current is led through the skin by way of an electrode, 1 square inch in area, a stinging pain is produced when it reaches a strength of 10 milliamperes, and the pain is unbearable with a strength of 15 milliamperes. To heat the skin appreciably, a strength of 400 milliamperes would be required. An alternating current of low frequency would be equally unsuitable to produce diathermy, because it would cause violent and intolerable contraction of the muscles before it attained a density sufficient to develop heat. If, however, the frequency of the alternation is much increased the current loses its power to stimulate the excitable tissues. If it alternates 5,000 times per second the muscles contract only feebly and the stinging sensation is not felt. If the frequency of alternation is increased to 50,000 per second there is no perceptible stimulation of the tissues. The density of the current can now be increased to a value which could not be tolerated in the case of the direct or low-frequency alternating current, and only a feeble contraction of the muscles will be felt. If the frequency of the alternation is further increased to, say, 500,000 per second, the current will lose all power to stimulate the tissues whatever its strength or density.

Such a current can be passed through the body and its density raised higher and higher and no sensation will be felt other than that of heat. The limit of toleration of such a current is determined only by the degree of heat.

The reason why a current which alternates with a very high frequency is unable to stimulate the excitable tissues is that as the duration of flow of the current in any one direction is made shorter and shorter, so must the current be made stronger and stronger if it is to stimulate the tissues, till finally a critical duration of flow is reached. If the current flows for less than this period, it has no power to excite the tissues, whatever its strength may be. The length of this critical period is not known in the case of the human subject, but it is extremely short and may be taken as 1/100,000th of a second. If the current oscillates more frequently than 100,000 times a second it will not stimulate the excitable tissues, and its strength may be increased till the heat which it produces is too great to be borne.

Such a high-frequency current will not produce the electrolytic changes in the skin and underlying tissues which a direct current, if applied with too great a density, is liable to bring about, with the formation of blisters and ulcers. The probable explanation is that the high-frequency current is unable to cause a migration of ions and the formation of new chemical compounds possessing caustic properties at the poles.

Apparatus for the production of diathermy.—To produce a degree of diathermy sufficient for medical purposes, an apparatus that can give a current of 2½ to 3 amperes is required. From what has been said it is evident that if a current of this magnitude is to be passed without danger through the body it must alternate at least 100,000 times per second. A current of this frequency of alternation can be obtained by means of a condenser discharging through an inductance. The device known as the d'Arsonval transformer, consisting of a pair of Leyden jars the outer coatings of which are connected by a stout wire solenoid, will provide a current of sufficiently high frequency of alternation. The current will, however, produce little or no diathermy because the oscillations are not sustained. The Leyden jars have a very small capacity, and the time which they take to discharge though the solenoid is exceedingly brief, viz. 1/50,000th of a second. During this period there is a train of high-frequency current oscillations. If the jars are charged from a large spark coil (as is usually the case when the d'Arsonval transformer is used for medical purposes) fitted with a mercury break which interrupts the primary circuit 100 times a second, the jars will be recharged the same number of times per second. There will therefore be during each 1/100th of a second a period of only 1/50,000th of a second occupied by oscillations. If a patient is connected to the ends of the solenoid for a period of 30 minutes, he receives the high-frequency current for only 3·6 seconds. Further, the Leyden jars are charged to an unnecessarily high voltage, while the current of discharge between the outer coatings of the jars reaches a strength of ½ ampere only, as measured by the hot-wire ammeter. A current of this strength, flowing for very brief periods with very long intermissions, cannot perceptibly heat the tissues. The modern diathermy machine has been constructed with the object of obtaining currents of sustained high-frequency oscillation and higher amperage so that the tissues can be sufficiently heated.

Construction of diathermy machine.—In the modern diathermy machine high-frequency currents are obtained on the same principle as that embodied in the d'Arsonval transformer, but there are the following differences in construction. The condenser has a much larger capacity. (In the machine to be exhibited its capacity is 0·6 microfarad. It is made of sheets of metal separated by mica.) It is charged from the main by way of a stationary transformer which raises the voltage of the current to 2,000. The charging current must be an alternating one. The condenser discharges across two very narrow air-gaps placed in series. The air-gaps lie between copper discs placed with their faces parallel and opposite to each other. The opposing faces, between which the sparks pass, are coated with silver. The width of each gap is ½ millimetre. With a transformer of this kind, supplied by a current from the main, the condenser is recharged as soon as it is discharged, so that there are uninterrupted chains of high-frequency oscillations in the solenoid. The current which passes to the patient is taken from a second solenoid, the extremities of which are connected to the electrodes. When the latter are placed on the body, the voltage between them is probably less than 1,000. In most machines it is possible to connect one of the electrodes to some intermediate point along the secondary solenoid so that a lower voltage can be obtained. A low voltage is advisable when it is desired to send the diathermy current across a narrower section of the body, e.g. from the front to the back of the knee. Further variation can be effected by altering the distance between the primary and secondary high-frequency coils.

Diathermy machines of different design vary in the methods of regulating the current passing to the primary of the transformer and the current passing to the patient. They also vary in the design of the spark-gap. The spark-gap is the "sensitive spot," and the slightest alteration in the width of the gap will considerably lower the strength of the current passing to the patient. The current will also be diminished if the spark-gap becomes too hot. In some machines methylated spirit is allowed to pass slowly between the metal discs. It is decomposed by the sparks and hydrogen is formed. This gas is a better conductor of heat than air. In other machines the air of the gap is replaced by coal gas, and the width of the gap can be adjusted while the machine is in operation. In others, a stream of air is directed over the metal discs by means of a fan.

Sensation produced by passage of the diathermy current through the body.—If the ends of the secondary high-frequency coil are connected to metal handles which are grasped in the hands none of the sensations commonly associated with the passage of electric currents through the body will be experienced. There will be no tingling, and no muscular contraction. At first nothing will be felt. Soon, however, a feeling of warmth will be evident, first in the wrists and then gradually spreading up

the arms. The wrists always feel the hottest because they form the narrowest part of the circuit traversed by the current. The blood is heated as it circulates along the arms so that the rest of the body is heated indirectly. If the handles are held for a few minutes, the whole body becomes hotter and the sensation is like that felt on entering a hot-house. The temperature of the body may be raised from its normal value (98·4° F.) to 100°, 101°, 102°, 103° F. or even higher.

Application of the diathermy current to the body.—If it is desired to raise the temperature of a part of the body a few degrees only, so that its vitality is not impaired, electrodes made of sheet metal are placed so as to include between them the part to be heated. They can be placed either in direct contact with the skin or with lint pads, soaked in strong salt solution, intervening. If the electrodes are not too small the density of the current passing between them will be low and the parts lying between them will be not unduly heated.

If, however, it is desired to raise the temperature of any abnormal tissue, such as a growth, to a degree sufficient to kill it, one of the electrodes is reduced to the size of a disc or button $\frac{1}{8}$ inch to $\frac{1}{4}$ inch in diameter. The current density will be very great in the region of this small electrode and the heat will be sufficient to coagulate and destroy the tissue.

Medical and surgical uses of diathermy.—A brief account of the uses to which diathermy has been put may be of interest, and two examples will be given. There is a very painful form of inflammation of the knee that is caused by the micro-organism known as the gonococcus. This organism thrives at the temperature of the body, but is very sensitive to a hotter surrounding, and it can be killed if the temperature is raised a few degrees. The knee joint can be heated through and through by the diathermy current and the organism can in this way be killed.

Diathermy has proved to be a valuable method of treatment of cancer and other malignant growths. It raises their temperature till they are coagulated and destroyed in situ. The application of hot cautery instruments to the growth would simply burn the parts where contact was made and the destruction would spread scarcely any distance below, because the tissue is a very bad conductor of heat. The tissue conducts the diathermy current, however, so that it is heated through and through and coagulated en masse, right down to the region where the density of the current is just too low to produce a sufficient degree of heat. The blood vessels and lymphatics in the growth are sealed, thereby lessening the chances of dissemination.

Historical note.—A short note on the history of diathermy may be appropriate because the preceding account suggests that high-frequency currents were introduced into medicine because it was desired to try the effect of heating the tissues through and through in the treatment of disease. This was not the case. Currents of high-frequency oscillation were first used for medical purposes in 1898 by d'Arsonval. He had previously noted that these currents possessed peculiar physiological properties and could modify the metabolic processes of the body. He had also observed that these currents could produce a sensation of "disagreeable heat." Nobody, however, could give a satisfactory explanation of their mode of action in producing physiological and therapeutic results. In 1907 Nagelschmidt, a Berlin physician, demonstrated that high-frequency currents could bring about a penetration of heat into the tissues, and he suggested their use in the medical treatment of diseases of the joints and the circulation. In 1908 von Berndt, von Preiss, and von Zeyneck published a paper on the uses of high-frequency currents for joint diseases, and they spoke of heat-penetration as the essential part of their action. Nagelschmidt designed the parent type of the modern diathermy machine which produces currents of sustained high-frequency oscillation. It was made by Messrs. Siemens Brothers. It was introduced into England by the late Dr. Lewis Jones, and its use for the first time in this country was demonstrated by Nagelschmidt in the Electrical Department of St. Bartholomew's Hospital in October, 1910. The original machine is still in use there, and several hundred patients, suffering from various diseases, have been treated by it.

In 1909 another diathermy apparatus was used in the Electrical Department at St. Bartholomew's Hospital. It was made by Schall, and it was fitted with a Lepel spark-gap. The latter was composed of copper discs separated by a washer of brown paper.

(The discussion on this paper will be found on page 358.)

SINGLE-IMPULSE RADIOGRAPHY (INSTANTANEOUS): ITS LIMITATIONS AND POSSIBILITIES.

By Robert Knox, M.D.,

DIRECTOR OF THE ELECTRICAL AND RADIO-THERAPEUTIC DEPARTMENT, CANCER HOSPITAL, BROMPTON.

(*Paper first received* 23 *March, and in final form* 13 *May*, 1918; *read at a Joint Meeting of* The Institution *and the* Electrical Section of the Royal Society of Medicine, 11 *April*, 1918.)

In the initial stages of radiography, radiographs were obtained by time exposures of considerable duration amounting to an hour or more. Ever since those days the tendency has been to shorten the time of exposure in order to obtain sharp detail in moving parts of the body such as the thorax or abdomen. Limitations of output by induction coils, and inability on the part of the X-ray tube to withstand the effects of passing a heavy current through it, for a time placed instantaneous exposures of any practical value beyond reach.

Sir James Mackenzie Davidson has shown that a revolver bullet can be radiographed in its flight over the surface of a photographic plate. The bullet in its flight broke the primary circuit of an induction coil, somewhat after the method employed by Mr. Boys some 20 years ago in his flying bullet photography. The flash resulting from the X-ray bulb in the secondary circuit gave a shadow of the bullet on the plate.

It is possible to produce a single-flash radiograph by a comparatively simple method—one given by Captain Kaye is to join the primary of a modern heavy-current induction coil or other high-tension transformer straight to the direct-current lighting mains with the usual fuses in circuit; when the current is switched on, the fuses are immediately blown, and the consequent interruption of the current produces a prompt discharge through the secondary winding and the X-ray tube in circuit with it.

Apparatus for Single-impulse Radiography. Development of the Method.

The first serious attempt to produce apparatus capable of dealing satisfactorily with the single-impulse exposure was made by Klingelfuss, who in 1901, by means of a "break" voltage due to a sudden interruption of the primary current of an induction coil, produced a brilliant illumination in an X-ray tube, which was sufficiently powerful to give an exposure on a photographic plate, the exposure time being a fraction of a second.

Drs. Albers Schönberg and Walter carried out experiments on similar lines. They produced a sudden interruption of the primary current by quickly withdrawing a metal pin immersed in a quantity of mercury. As a result of these experiments an apparatus was constructed and placed upon the market, a number of these installations being in use at the present time.

The induction coil of this apparatus was of very large dimensions. The single-impulse interrupter consisted of a glass vessel containing a quantity of mercury. A dielectric of paraffin oil was used, and into this glass vessel was inserted the mechanism for operating the single impulse. A single-flash impulse was produced by lifting the lever of this single-flash switch to the top of its travel and allowing it to fall back by gravity without a pause; and if everything were correctly adjusted a broad thick spark of about 6 or 7 inches in length would be obtained between the spark pillars of the induction coil, this impulse being used in the X-ray tube.

A 7-inch parallel spark was about the maximum that this apparatus would give, and the exposure was roughly calculated at about 1/200th of a second. With such an exposure it was possible to obtain radiographs of the thorax and other parts of similar thickness, but not of the abdomen. The milliamperes could not be measured because of the shortness of the exposure, and partly owing to the presence of reverse current.

The drawback to this apparatus was the fact that the human element entered largely into the operating of the single-flash switch; that is to say, the operator controlled the speed of the "make" current, and to some extent the "break," by the time that he took in raising the lever, and this caused the time period of the flash to be subject to variations. An exact repetition of the exposure could not be made with any degree of certainty.

Koch in 1907 endeavoured to obtain a single-flash interruption through breaking a copper wire in the primary circuit of the coil by means of a pistol shot. The results of these tests were, however, unsatisfactory, chiefly because of the shortness of the interruption and the small size of the coil employed, the energy of the current impulse obtained in the X-ray tube not being sufficient to produce a photographic effect of any value.

Dessauer developed this process and introduced into practice in 1909 an apparatus for obtaining instantaneous interruptions by means of a mercury switch in which a rod was suddenly withdrawn from the mercury by means of a spring. No uniform results could be obtained, and this led to Dessauer investigating a system for breaking the primary current by causing a thin wire to melt rapidly by an overload of current. The wire was enclosed in a cartridge similar to the well-known cartridge fuse. The fuse system consisted of a fine fuse wire 0·3, 0·4, or 0·5 mm. thick, enclosed in a glass tube forming the cartridge. On closing the main switch the core of the induction coil is magnetized and the current in the primary circuit grows until the fuse wire is overheated and an explosion occurs, which by rapidly interrupting the primary circuit induces an impulse in the secondary circuit. It is claimed that a current of 200 milliamperes was obtained for a spark-gap of 16 inches, or about 150

milliamperes through a soft tube, that is, one suitable for thorax exposures. It was estimated that the primary current would rise to about 250 amperes before the explosion of the fuse, but on account of the short period of time (calculated to be about 1/100th to 1/300th of a second), it was unnecessary to fuse the main supply circuit for more than 40 or 50 amperes. The duration of the exposure was calculated by means of a rotating film exposed through a lead diaphragm. Such an exposure with this apparatus was capable of producing a radiograph of the thorax of a patient of medium build.

A later development of this type of apparatus consisted of using a number of fuses in succession, these being exploded automatically by means of a mechanical contrivance. This made it possible to obtain exposures of organs like the heart and abdominal structures with ease. If one exposure was not sufficient another could be made rapidly. Other workers achieved the result by using varying thicknesses of fine wire, the intensity of the exposure varying with the thickness of the wire. The drawback to this method was that exposures were not always the same because of the variations in thickness.

The forms of apparatus considered so far are based upon the principle of producing in the secondary winding of an induction coil an electromotive force of short duration and great magnitude by quickly breaking the primary current.

A further development of the method led to the production of the Siemens impulse process. I am indebted to Mr. Howard C. Head for the description of this apparatus. This in brief is based upon the utilization of the impulse which is generated in the secondary windings of the coil when the primary current is suddenly commutated. The commutation of the primary current consists of two distinct processes, i.e. breaking the current and making the same current but in the opposite direction. During the first process a "break" voltage is generated, and during the second a "make" voltage. This "make" voltage is now in the same direction as the "break" voltage, owing to the current flowing in the reverse direction after commutation. Therefore, commutation causes two consecutive impulses to be developed which, however, combine in one impulse when the two processes occur rapidly, namely, in about 1/100th of a second, and the combined impulse is equal to the sum of the two impulses. Therefore, with one commutation a current double the effect due to the "break" voltage is obtained, and the same effect as with the former processes is obtained with the expenditure of a considerably smaller load on the primary of the induction coil.

In order to obtain this enhanced effect it was necessary for the "make" voltage to be equal to the "break" voltage and to construct an automatic switch to serve as a commutator, so that the two impulses combined in one impulse without interruption.

Although it was a fairly simple matter to construct a switch to carry the large quantities of energy necessary for the safe commutation of the current, a further problem had to be considered in connection with the construction of the coil. One has to consider the fact that the number of primary turns necessary to obtain an intense magnetization, and yet sufficiently small to produce an intense opening voltage, had such a large self-induction that the primary current and consequently the magnetization of the iron only rise very slowly after the current has been commutated, and therefore the secondary "make" voltage assumes too low a value; but this difficulty was overcome by constructing the coil so that as a result of a small self-induction the magnetization rose rapidly. Further, measures had to be taken in order to neutralize the various secondary phenomena noticeable in the process of commutation.

It will be understood that the commutation of the current through the primary of the coil must be preceded by the make of the current, and the commutation must naturally be followed by switching the current off, and as secondary electromotive forces are produced when switching on and off, and as these are opposed to the electromotive forces generated in the commutation, it is necessary, in order to protect the X-ray tube against inverse radiation, that the processes of switching on and off be carried out slowly. This is arranged for automatically by the single-impulse switch, so that it is impossible for the operator to produce inverse radiation in the tube by the introduction of the human element into the mechanical working of the switch.

The switch is operated by rotating a handwheel through about one-quarter of a revolution. The commutator is then automatically operated, and this is followed by the automatic resetting of the switch for a second or further number of exposures.

Originally an induction coil was used in connection with this form of single-impulse apparatus, but it has since been found that the transformer with a closed magnetic circuit is more suitable, and a combined apparatus has been constructed in conjunction with a high-tension rectifier, the transformer being used in conjunction with this apparatus for ordinary work and the single-impulse apparatus for its special purpose. This apparatus may be considered to be a universal apparatus capable of dealing with all work necessary in X-ray technique, i.e. X-ray therapy, as well as radioscopy and radiography.

The main differences between a standard high-tension rectifier used for ordinary radiographic work and one specially constructed for single-impulse exposures are:

(1) The transformer of relatively small output is replaced by one of much greater capacity.
(2) The single-impulse switch is an addition.
(3) A change-over switch is inserted in the primary circuit of the transformer.
(4) A high-tension change-over switch is provided for altering the connections (passing from the rectifier to the X-ray tube) to the direct connections of the secondary of the transformer. That is, the X-ray tube is connected directly to the secondary terminals of the transformer instead of to the rectifier which is used when the apparatus is worked in the ordinary way.

The combined apparatus referred to can be connected to a direct-current supply, and further developments have made it possible to construct an apparatus which can be directly connected to single-phase or three-phase alternating current. This is based on the idea of connecting the primary coil of the transformer to the alternating-current supply for a short time, and of impressing upon the tube the secondary voltage generated during this time and rectifying it by means of a rectifier.

Shorter exposures are claimed than 1/100th of a second, but for practical purposes until proof is forthcoming it may be assumed that the average length of a single flash is in the neighbourhood of 1/100th of a second.

Comparison of the Exposures obtained from the Two Sets of Apparatus.

(*a*) Single-impulse outfit with mercury dip interrupter.
(*b*) Siemens impulse outfit.

The experiments were conducted with moving objects. The first slide shows two pieces of lead suspended from a cross bar by a piece of string, and the objects were caused to swing in front of a photographic plate while the exposure was made. A double shadow of the pieces of lead and the string is obtained when the Siemens impulse apparatus is used.

It was somewhat difficult to explain the double shadow, and a further experiment was therefore made by placing a metronome in front of a photographic plate. The results obtained are shown in slides prepared from the negatives. These are extremely interesting. They show that the single-impulse pictures obtained with the first set of apparatus (*a*) are really due to one impulse in the secondary circuit. Those obtained with the Siemens impulse outfit all show a double shadow except in one or two obtained when the pendulum is approximately at rest at the end of its swing.

Possibly the mechanism at work in the production of the impulse or impulses—i.e. the commutation of the current whereby a "make" is added to the "break" impulse, and the fact that these are not actually combined in one impulse—may explain the double shadow. The possibility of the double shadow being due to movements of the pendulum during the exposure cannot, however, be excluded. The matter is worthy of more accurate and extended investigation, and I shall, when it is possible to get the time to do so, repeat these experiments with properly constructed apparatus.

In this relationship it is interesting to record a number of plates obtained with the metronome and exposures from the electrolytic interrupter. These all show a number of distinct impressions of the pendulum on the plates, and they vary in number with the rapidity of the interruptions in the current.

I purposely refrain from attempting to estimate the duration of the exposures from the two sets of apparatus because I realize that the experiments up to the present are far too crude to allow of such estimation, but I think they clearly indicate that the exposures obtained from apparatus (*a*) are much shorter than those obtained from apparatus (*b*). This is borne out radiographically by a large number of plates obtained from both sets.

Up to the present I have always attributed the better quality of negatives obtained with set (*b*) to the greater intensity of the discharge, but after considering the metronome experiments from the two sets of apparatus I am inclined to think that the longer exposure with set (*b*) is the real explanation of the difference. I shall have the two sets carefully tested to settle this point.

Types of Single-Impulse Apparatus.

I have two different types of single-impulse apparatus under my care: (*a*) with a mercury dip interrupter and (*b*) a Siemens single-flash coil outfit. These have been in constant and regular work and have given most satisfactory results up to the limitations of their electrical capacity. I shall indicate later what I consider to be the most suitable type of apparatus, and I shall try to indicate the quantity of current in the secondary necessary for the production of high-class radiographs of any part of the body by means of the single-impulse exposure. It may, in the absence of definite proof, be assumed that the secondary current in these exposures is in the neighbourhood of 200 milliamperes.

To ascertain the radiographic efficiency of these sets of apparatus an extensive set of experiments was carried out. These experiments resolved themselves into an attempt to ascertain (1) the best conditions for working, (2) the testing of the uniformity of the discharge over a large number of exposures, and (3) the value of intensifier screens for use with single-flash exposures. A number of well-known X-ray plates were used in these experiments. It was also hoped that the experiments might lead to suggestions for improving the apparatus, might be a means, in fact, of ascertaining the minimum output with which it would be possible to do all forms of radiographic work, and gradually to lead to a standardization of exposures.

The apparatus was used with two forms of X-ray tubes, namely—

(*a*) The gas tube, Macalister Wiggin tungsten target, and
(*b*) The Coolidge tube.

With the gas tube a number of tubes approximately in the same state of vacuum were used. The results obtained with these are extremely interesting.

The Coolidge tube is undoubtedly by far the best and most reliable tube to use for this class of work because of its great flexibility, its durability, and the great ease of manipulation which it allows. With one tube any number of exposures may be made with the tube emitting rays of varying penetration; a number of lantern slides will best illustrate these points.

The analysis of these experiments shows a remarkable uniformity of the discharge, even when allowance is made for the possibility of photographic error.

Indication for Increasing the Output of the Secondary Circuit.

The first desideratum is that the output would be powerful enough to give perfect radiographs without the use of the intensifier screens. Good though the plates obtained with the screen are, it would be a great help in technique if it could be dispensed with altogether; at present this cannot be done because the apparatus is not powerful enough. A consideration of the plates shown will prove this point. In all the exposures made at a distance of 1 foot, without an intensifier screen between the surface of the plate and the anticathode of the tube, the exposure is nearly a full one. At this distance a good deal of our work could be successfully carried out if it were not that the distance for obvious reasons is impracticable except for very small parts. At a standard distance of 2 feet the output requires to be increased at least four times, and for 3 feet at least nine times. The latter is the better distance for standard work, but that is not all, for it may be advisable to work at a distance of 6 feet, in heart work especially. I leave it to the electrical engineer to calculate the size and the capacity of an apparatus capable of dealing efficiently with the thorax of a 16-stone man at a distance of 6 feet between the anticathode of the tube and the surface of the plate, basing the calculation on the results shown on the slides obtained from the penetration gauge and other experiments.

The late Mr. Duddell in his Presidential Address to the Institution referred to a transformer which weighed half a ton; perhaps some member can state what output such a transformer would be capable of and if it would stand any chance of complying with the requirements mentioned above.

Captain Kaye in his book on X-rays throws out a suggestion which I hope soon to see an accomplished fact. "Given a closer co-operation between the medical man and the electrical engineer, mammoth apparatus and extraordinary results may be looked for in the future." The above proposition is a sufficiently difficult one for the present, but I can foresee in the near future even greater demands upon the resourcefulness of the electrical engineer. A great deal of work is being done at present in the radiography of metals, and an apparatus may be required which will penetrate and give a photographic record of a piece of metal 3 or 4 inches in thickness. The single-impulse exposure may be extremely useful in this direction. What should be the capacity of a transformer to enable us to obtain satisfactory pictures of metal in thickness from 1 inch to, say, 4 inches?

The single-impulse apparatus of the present day is not capable of dealing with this proposition. The greatest spark length I have been able to obtain from a single-impulse exposure through a Coolidge tube was about 12 inches. Several of the penetration experiments shown were obtained with a spark length of from 9 to 10½ inches—yet in these pictures a perfect record of the lead plugs and all the layers of aluminium was obtained. The density in the lower registers is much less than in those obtained with a short spark length and a softer tube.

A slide illustrates single-impulse exposures from different gas-tubes approximately in the same degree of vacuum; these show variations, but all indicate good penetration in the low registers and a fair amount in the high. No. 6 was obtained with a tube in a higher state of penetration. All of these would give a good picture at that distance.

Another slide shows six exposures on six plates at distances of from 1 to 6 feet, showing the regular diminution of intensity as the distance increases; the plates have not been developed to infinity.

The next slide shows an experiment with a Macalister Wiggin tube, 6-inch spark length; none of these plates show sufficient exposure for the production of a good radiograph without an intensifying screen.

A further slide shows a similar number of plates taken with No. 1 single-flash outfit at a distance of from 1 to 5½ feet. These plates have been fully developed. No. 1 at 1 foot gives a full record of exposure and is sufficient for most of the radiographic work in special subjects at a distance of 1 foot.

Most if not all of the single-impulse work of the present day is done in combination with the intensifier screen; this is always used in thoracic and abdominal work.

A number of experiments were carried out on similar lines to those conducted without the use of the screen; these are shown for distances of 1 to 6 feet and demonstrate the value of the intensifier screen and the shortening of the exposure when it is used.

No. 1 at 1 foot is greatly over-exposed. No. 2 is about the correct exposure for abdominal and thoracic work.

The average distance for chest work is between 2 and 3 feet, varying slightly with the size and thickness of the subject.

At 6 feet the exposure is practically valueless for radiographic work.

Experiments to show the differences obtained when exposing through the Screen on to the Plate and through the Glass on to the Plate and Screen.

An interesting set of experiments demonstrates the effect of passing the rays through the screen on to the film, and the gain in sharpness of the detail when the rays do not pass through the screen but through the glass to the film and on to the contiguous surface of the screen; this does not require elaboration here, though it is of great interest from the radiographic point of view.

The next set of experiments was carried out to demonstrate the value of being able to work at greater distances than 1 to 2 feet. The same object has been radiographed at a distance of from 1 to 6 feet from the anticathode of the tube. The explanation is graphically given on the diagram shown on the next slide.

The practical outcome of this experiment is that for all distances under 6 feet a certain amount of dis-

tortion is produced according to the distance of the object from the plate. Thus in an average thorax the anterior chest wall is on the plate while the posterior wall is at least 6 inches from it. It is easy to realize that that distortion must occur—this is demonstrated in the case of the heart when X-rayed from back to front, and vice versa. Two radiographs show the difference in the size of the shadow of the organ in the two positions; the posterior view is at least one-third larger than the anterior one.

In practical work the distortion may be allowed for, but when accurate measurements of the heart are required the greater distance of 6 feet would to a large extent do away with the distortion and give the heart approximately its normal size on the plate.

These experiments lead us to the conclusion that we need an apparatus which will enable us to work satisfactorily at a distance of 6 feet for these conditions. The solution of this problem I can confidently leave to the electrical engineer, and in time I hope to see realized the mammoth machine and the extraordinary results which will automatically follow from its production.

Apparatus powerful enough to enable us to work efficiently at a distance of 6 feet from the plate by the aid of intensifying screens for thoracic and abdominal work would also be powerful enough to allow of work being done on other parts at a distance of 2 feet without the screen; then it should be possible to do all forms of radiographic work by the single-impulse method.

The great advantage over work which is now carried out by time exposures will be that there will be no plates spoiled by movement on the part of the patient. With the apparatus at our command it is possible to get satisfactory radiographs of parts which are not too thick; arm and leg bones are radiographed and pictures obtained which are perfectly sharp in detail.

The value of single-impulse exposures is demonstrated in the radiography of children; in infants the detail of bone is excellent, chiefly because the rapidity of the exposure eliminates voluntary or involuntary movements on the part of the patient.

No hospital which especially deals with children's diseases can afford to do without a single-flash apparatus. These young subjects will not keep still during an exposure. With a single-impulse machine we can allow a child to be upon the plate and move about—the exposure is made while the child is actually on the move—yet the picture obtained shows no trace of movement. A slide illustrates this point; a child who had swallowed a coin was placed upon the plate, movement going on all the time the exposure was made. The picture is practically sharp; no trace of movement is seen anywhere.

By using the maximum power with a long spark equivalent gap, detail may be brought out in fairly thick parts. When one exposure is not quite sufficient, a second following immediately upon the first exposure may be sufficient to increase the effect upon the plate sufficiently to give the necessary detail. The lantern slides show these points well.

Single-impulse Radiography in the Examination of Bones and Joints.

While up to the present the uses of the single-impulse exposure have been practically confined to the examination of the thoracic and abdominal organs with the intensifying screen, there are possibilities for its use without the latter. This is particularly applicable for instance to the examination of the bones and joints of children where the shortness of the exposure eliminates the ill-effects of movements on the part of the patient. In adults the method may be used for the radiography of the bones and joints, where if one exposure is not sufficient to give the necessary detail two or more may be used in quick succession.

In order to obtain the necessary penetration the spark-gap may be increased up to 10 inches when a Coolidge tube is used. To demonstrate the effect of increasing the spark length a number of experiments were conducted. A penetration gauge and a dried femur were used in these experiments.

The bone was radiographed along with the gauge with the spark lengths indicated below; the heating current employed in such exposure varied as the spark length increased. The primary current was the same in each exposure.

The following spark-gaps were employed: 2 inches, 4 inches, 6 inches, 8 inches, 10 inches.

The lantern slides show the increase in detail as the spark length increases. The penetration gauge gives a record of the penetration obtained in each exposure. These provide a permanent record which should prove useful when a standardization of exposure is contemplated.

Mr. Luboshey has kindly supplied me with the following interesting comments on the plates obtained in the experiments. They particularly deal with the photographic value of the results and appear to indicate that already a step has been made in the direction of standardization.

"Herewith are some notes referring to the test negatives of the single-flash exposures. You will of course note that I have taken particular care in getting the average quality, owing to the fact that some of the negatives were according to the present method of work considerably farther developed than they should be, like the larger set that you have, which is very nearly what is wanted, and therefore, in judging those while reading the scales, this should be taken into consideration. It is quite astonishing to what degree of accuracy some of the sets show the variation of the exposures. I believe from the first set—that is, the largest one, which includes the bone and the scale as well—one can actually judge to what extent the single-flash exposures, as shown on these negatives, are within practical use for deciding what spark-gap to use for any particular case. When all these negatives are put in one line it is possible to draw a very accurate curve of what happens to the photographic plate when only the length of the spark-gap is varied. You will note of course that I have taken as a guide for my exposures the absolute opacity and the absolute transparency.

The first stages of the point No. 1 just show the square on the positive on the white paper, representing the first stage of beginning to darken as compared with white, and the No. 6 point is just showing the square, as compared with absolute transparency in the negative or blackness in the positive. This is the negative which is marked 10-inch spark-gap. Each succeeding negative shows clearly the deduction of light at a ratio fairly accurate as compared with the next succeeding exposure, and so on up to the whole scale of 10, 8, 6, 4, and 2 inch spark-gap, and, if you will put them all in one line, you will find that you can very nearly make a horizontal scale from all five of them, almost equal to the vertical scale on the last. The conditions necessary to accomplish this depend of course very greatly upon the accuracy of the measurement of the spark-gap and upon all the negatives being developed together and the prints made, as I have done in this case, from all the negatives at once by the same light and with the same time of development, temperature, etc., so that each negative receives absolutely equal treatment. In the subsequent exposures it is very interesting to note how the middle tints, such as 3 and 4 on the scales, indicate fairly evenly and seem to show a very marked characteristic, declining and increasing abruptly on either side of the middle scale. It may be interesting for you to know that the present method of developing negatives has a very great tendency to increase unnecessarily the contrast of any scale, and this you can also very easily see by comparing the largest set of negatives with one of the smaller sets where the scale is somewhat steeper; but, as I have mentioned, I have been very particular to give to the prints as nearly as possible only correct development and exposures, without any individual dodging of any of the scales whatever. The best paper for the purpose of giving the nearest reproduction of the scale is Kodura paper; most of the others seem to exaggerate the steepness of the curve. I hope this will give some idea to what extent it is necessary to keep the photographic side of this work as constant as possible and to show to what degree of accuracy the electrical side of the work can be carried under the present conditions. These negatives in any case certainly show me to what extent variation of the spark-gap, distance from the tube, and other factors can already be controlled."

A number of radiographs obtained from the living subject illustrate the possibilities of doing ordinary X-ray work with the apparatus at present in use—they also demonstrate that more powerful apparatus is necessary if all forms of X-ray examination are to be conducted by this method.

Standardization of exposure.—The possibility of standardization of exposure is placed within our reach, and when the greater output is available it should be possible to state definitely what exposure would be necessary to produce a useful radiograph of any particular part.

There are other factors which would require to be standardized. By means of a fine scale on the regulating rheostat in the primary it would be possible to regulate the current sufficiently to allow of small variations in the primary circuit.

The heating current in the Coolidge tube should also be capable of very fine adjustment.

An accurate record of all data for a particular exposure would facilitate the reproduction of the conditions at a subsequent examination.

The primary current could be arranged for by placing the regulator on the same stud of the resistance; the heating current would also correspond. The distance between the anticathode and the plate would be constant.

A table could be produced which would state definitely the conditions necessary for a particular part if all the factors corresponded and the apparatus worked accurately; then it should be possible to turn out standard results with a fair degree of accuracy.

These results are all within our reach when we obtain the apparatus capable of giving a much larger output than that at present in use.

Special Points in the Development of Single-impulse Radiographs.

Plates exposed by the single-impulse method require to be developed for a longer time than those exposed by the time method.

Care must be exercised to prevent fogging by the dark-room light or chemical fog from prolonged development. The plate should not be exposed to the red light for the first 3 or 5 minutes in order to obtain the maximum photographic effect.

Practice in the manipulation of the tubes and the selection of the proper spark length for the tube in particular work, care in the development of the exposed plate, and choice of the part for the exposure will lead to a great improvement in the average results. I am fully convinced that in the single-flash method we have the beginning of a standardization of exposures, and when the apparatus at our command is more powerful than that of the present day I feel sure we shall have gone a long way towards the accomplishment of the standardization of technique and exposure.

I trust that I have succeeded in placing before engineers the need for practical help in the development of electrical apparatus for the energizing of the X-ray bulb. The examples I have shown are average results obtained by the use of single-flash exposures. Compared with the examples produced in the early years of X-ray work they mark a great advance in a comparatively short period of time.

Standardization of Apparatus and Technique.

It has been pointed out that the apparatus at present in use is not powerful enough to meet the requirements of present-day radiography. This is clearly established by the experimental work shown by the lantern slides, radiographs, and prints. It has also been indicated that it would be necessary to increase the power of the machine at least four times that at present in use, and for distance work, i.e. at 6 feet, proportionately more power would be required. This problem should readily be solved by the electrical engineer, it being merely a matter of calculation and possibly experimental work to produce the apparatus satisfactorily. It would be of great value to radiologists

if a standard method for the production of high-tension currents could be evolved. Whether it should be produced by the coil or the high-tension transformer is a matter for the engineer. My own impression is that the high-tension transformer with a rectifier is by far the most satisfactory method at present available.

An important step and one which would go a long way towards solving our difficulties would be for the engineer to tell us definitely the best possible conditions under which the transformer would work, what is the best voltage for the supply, and whether it should be continuous or alternating current. When this point is settled then we should be in a position to ask the consulting engineer who is responsible for the electrical installation of our hospitals to supply a sufficient quantity of power for our purpose in the X-ray department.

An example of the need for this can be quoted. A large general hospital, recently equipped, installed its own electrical plant, and the engineer originally arranged for a supply of continuous current at 50 volts. This pressure was, fortunately for our purpose, raised to 110 volts. What voltage is, however, the best for our purpose, 100 or 240 volts? What type of transformer is most efficient? I shall not say economical, because I do not think we should allow economy to influence our judgment in these matters.

If we had a standard specification for current supply and apparatus it would strengthen our position when approaching hospital committees with proposals for the equipment of X-ray departments. With this specification in general use and adopted throughout the country, a great step towards standardization would have been made.

The necessary apparatus could in time be also standardized and the X-ray tube would quickly follow in the same direction. As has been shown, the standardization of the exposure is well within reach—even with the apparatus in use to-day.

In the next decade or two, equally great advances may be made and possibly the apparatus of to-day may be superseded by something revolutionary in type. Provided the result is realized, it matters not how great may be the alterations in types of apparatus.

The future development of single-impulse radiography will be along the lines I have indicated, an increase of the output for thoracic and abdominal work to enable us to dispense with the use of the intensifying screen. When this is accomplished we may expect to see it adopted for general work.

Discussion at Joint Meeting of the Institution and the Electrical Section of the Royal Society of Medicine, 11 April, 1918.

The President: To-night we are in several ways making a new departure in regard to our meeting. In the first place we have papers dealing with the applications of electricity to curative purposes and to investigatory purposes in connection with the cure of diseases. I think I am right in saying that only once since the Health Exhibition have we had a paper dealing with matters of this kind. The Council thought that if we could get papers showing the present state of knowledge in some of the branches of these applications, it would be a matter of great interest to our members, and that it would also bring us into touch with that profession which we all now admire more, if possible, than ever, since we have seen what its members have been able to effect during the war. Another departure is the association with our meeting of an exhibition of apparatus. In this hospital (The Cancer Hospital, Fulham-road, S.W.) there is the finest collection of X-ray and other apparatus connected with the subject of the papers existing anywhere in this country. And for that reason we have made a third departure from our usual practice, by meeting in a different place and at a different time.

Dr. J. Metcalfe: The subject of Dr. Knox's paper is of very considerable interest to me because I had estimated the advantages of this form of radiography a considerable time ago. I obtained from Messrs. Siemens some nine months before the war an apparatus of the transformer type like the one which Dr. Knox showed on the screen, and with the limitations mentioned by Dr. Knox I have been extremely pleased with the mechanism, which has required no repairs whatever. As Dr. Knox has said, however, the apparatus undoubtedly has many limitations. Its great advantage is in the examination of the heart, since to get a very sharp and definite contour of the heart it is necessary to have an apparatus that is absolutely instantaneous. And I think and hope that by the single-impulse method of radiography it will be possible in the future not only to make occasional pictures of the heart, but to formulate a definite system of diagnosis of heart disease from a series of pictures of this character. We can even now make excellent heart pictures having, as Dr. Knox has shown us, very definite outlines, and if one studies those outlines very carefully one can read into those heart pictures many of the appearances that would result from the clinical observation of disease. So that for the heart this is undoubtedly the best method of examination. There is of course the question of the screen. We cannot make good pictures by a single-impulse method without an intensifying screen, and to get a good picture at a considerable distance—say 6 feet—we require more electromotive force than can be obtained by the single-impulse method, and I think in that case we shall require two intensifying screens. I have lately been doing some work with the Austin Edwards film, which is a sheet of celluloid with a coating of emulsion on each side. If we use two intensifying screens we intensify on both sides, and get undoubtedly a very much stronger picture than if we use only one screen. But the difficulty to my mind seems to be in the matter of the casette. If the ordinary class of casette is used, in putting a large plate into the

casette we get a fairly accurate apposition between the surfaces. The film being so much thinner the apposition is, however, not perfect. Some of the intensifying screens are also rather thick and rigid and do not therefore make such accurate apposition, so that one very often gets blurring and shadows of a rather peculiar character, which certainly spoil the picture as a picture, although they do not perhaps interfere with the question of diagnosis. In my opinion, however, it is not necessary to examine bones such as those in the arms, legs, etc., by single-impulse radiography. By rapid instantaneous radiography, with an exposure of a fraction of a second, or even an exposure of one second, we get a wealth of detail in the bones that I think cannot be surpassed by any method of single-impulse radiography. But in the case of examinations of the stomach and intestines, undoubtedly the single-method impulse is of the greatest possible utility. The difficulty is, as Dr. Knox has said, that one requires to bring the tube so close to the patient that it sometimes becomes almost dangerous to use it, and the patient does not like it. Moreover, the field of vision is limited. Of course the insertion of the intensifying screen, and its removal, and the necessity of going into the dark room, are a great nuisance, besides taking up a great deal of time. Undoubtedly what we want to get—and what we no doubt shall get in the future—is an enormous machine without these limitations; and I have no doubt that, in time, electrical engineers will be able to produce a machine which, without the use of any intensifying screen, and without any laborious methods of applying the tube, by a long-distance exposure will enable us to make a standardized picture of any part of the body, i.e. a picture which any radiographer can compare with any other picture and thus make a reliable diagnosis.

Dr. E. S. Worrall: Dr. Cumberbatch says in his opening remarks that "Heat is a valuable therapeutic agent, and it has been used in the treatment of disease for centuries," and such indeed is the case. Use has been made of sun baths, Turkish baths, electric radiator baths, hot water baths, poultices and fomentations, and even moxas and actual cautery, the heat, as such, being brought to the surface of the body by radiation, convection, or conduction, or concentrated on the part treated by reflection or refraction by means of a lens. And if the part we wish to treat is some distance beneath the surface the heat can only reach it by means of (1) conduction of the tissues, which latter especially the skin are poor conductors, but do conduct, and (2) diathermancy. In the process described by Dr. Cumberbatch we have an entirely new way of heating the deeper tissues which depends neither on conduction of heat nor on diathermancy. He says that the name diathermy implies "through and through heating"; but this is exactly what the chef accomplishes whenever he cooks a joint. For though, as has been pointed out, the tissues are but poor conductors of heat, yet they do conduct and exhibit the property of diathermancy, otherwise the chef's joints would always be raw in the middle. The chef cooks his joints through and through, i.e. diathermizes them, yet he does not resort to the process we are considering, although this might be used for the purpose. This process then is not diathermy but something else. Heat is not brought to the surface by any of the methods of propagation I at first mentioned, and is not passed into the deeper parts by conduction or diathermancy, but is actually generated in the tissues themselves owing to the resistance they offer to the passage of the particular kind of current used for this purpose, just as a protecting fuse is heated to the melting point, or the filament of an electric lamp is heated to a state of incandescence. If the white of egg be placed in a glass vessel of such a shape that the albumen forms two lakes with a narrow canal joining them, and the electrodes of this miscalled diathermy apparatus be placed one in each lake and the current turned on, we find the albumen forming the canal is first coagulated, and if the current be then turned off we shall find that the electrodes are comparatively cool, as also is the albumen immediately surrounding them, whilst that forming the canal is cooked. Do not let us forget our natural philosophy and get muddled in our physics. Diathermancy in the case of heat is equivalent to transparency in the case of light. It refers to transmission of heat. Similarly, athermancy in the case of heat is equivalent to opacity in the case of light. In the subject we are considering we have to do with the transmission of an electric current not heat. The heat is produced as an effect of this transmission of current and is entirely endogenous, just as much as heat of the body generated by exertion or food is endogenous. I submit, therefore, that this process we are considering is not diathermy but is endothermy and that this name correctly describes the process and should be used when referring to it. Dr. Cumberbatch says, "In the most recent method heat is applied through the agency of an electric current (of special kind)." I protest that heat is not applied. Again he says, "This method of applying heat to the body differs from all others in that it causes a rise of temperature of the deep-lying tissues as well as those on the surface." I have remarked that most of us like our joints cooked through and through and we expect our cooks to achieve this without having to resort to this particular apparatus, which could be used for the purpose. I have used endothermy (if I may be allowed to re-christen the process) for some years though not very extensively, yet in a variety of cases and experiments and with gratifying results. In using this process it is very necessary in certain regions of the body to bear in mind that the maximum heating effect takes place at the smallest cross-section of the part under treatment, for here the current lines are crowded together, or in other words the current density is greatest. We have in endothermy two methods of treatment: (1) The medical, in which heating effects are obtained with a local hyperæmia and a local elevation of temperature which persists for some time after the application. Endothermy thus used has a marked power in soothing pain in neuralgia, lumbago, sciatica, and some neurites. Using large electrodes we may warm up the chest, liver, or a knee joint. Pain in a joint affected with gout may be considerably relieved in a chronic case, possibly

the gouty deposits re-dissolving owing to the increase of temperature produced. The heart's action may be considerably modified in frequency and force by using two large electrodes one in front and one behind the chest. And (2) the surgical method of endothermy enables us to perform many operations without the loss of blood and with less risk of disseminating infection, the mass dealt with being coagulated before being removed or thrown off. By using a very small metal spatula or needle for one pole the current may be so concentrated on a small area of the flesh that it can be charred or burnt, not merely epithermized, but being in contact with air actually combusted. By suitably regulating the current, deep incisions may be made without hæmorrhage. Using a large active electrode one can coagulate a growth to a desirable depth and allow it to be thrown off. I have used this in dealing with inoperable malignant disease of the floor of the mouth, also in a case of malignant ulcer at the base of the tongue, giving considerable relief in this case and enabling the patient to swallow more easily, where he had previously great difficulty in taking food.

Mr. W. E. Burnand: The first point that occurs to me in connection with Dr. Cumberbatch's paper is that a medical man using this process might find it useful to be able to visualize the distribution of current between the two electrodes, especially if these are of small size, since the current then does not flow in straight paths as in the case of current flowing through wires. The electrodes being surrounded by matter having a conductivity of at any rate the same order in all directions, the distribution of current will be very similar to the distribution of magnetism between the poles of a magnet. This suggests the use of iron filings sprinkled on a smooth piece of cardboard or smooth paper, the latter being held over two pieces of magnetized steel the size and shape of the electrodes. The filings will then give a very good picture of the distribution of force between the poles, both as to magnitude and direction. If the poles are separated by a distance of more than a few diameters from one another, the force (or current as it would be if these poles represent electrodes) is much more dense about the pole surfaces than in the space between, becoming less dense as the distance from the electrodes is increased, thus showing that little direct heating of the tissues between the electrodes can be expected under these conditions. If, however, the electrodes are brought close together, say within one or two diameters, the distribution of current in the space between them is much more concentrated, showing that under these conditions it may be possible to heat the tissues between to a higher temperature than the electrode surface, especially if the electrodes themselves are of silver, which has a high conductivity for heat. On this question of local heating, it might appear that with four electrodes situated as near as possible to the four corners of a square and numbered consecutively 1, 2, 3, 4, if corners 1 and 3 were used as a pair of electrodes, and 2 and 4 as another pair of electrodes coupled to an independent source of current supply, we should get double the heating effect in the space between with the same electrode density as before. What happens, however, with direct current, or with alternating current in which the supplies to the two pairs of electrodes are in phase, is that the current passes mainly from corner to corner leaving the centre with less current than if one pair of electrodes were used. This will be clearly seen from an iron-filing experiment in which four magnetized electrodes are arranged with alternate polarity. One way to get partly over this would be to arrange for the supplies to the two pairs of electrodes to be out of phase with one another. Thus if the two supplies were 90 degrees (electrical) out of phase the heating effect in the internal space ought to be about 1·4 times that due to one pair of electrodes if the tissue were of equal conductivity in all directions. As, however, we know that the conductivity varies with the direction of the fibre and also with the nature of the tissue, the improvement might be expected to be only from 10 to 25 per cent instead of 40 per cent. A method of getting still further heating of the tissues would be to have two or more pairs of electrodes and connect these pairs by means of a rotary switch to the source of supply rapidly one after another. A much larger current could thus be passed without heating the electrode surface excessively, and with a proportionate increased heating in the tissues relatively to the extra current passed. I think that from two to four times the amount of heating possible with one pair of electrodes might be obtained in this way. The difference between the effects observed with high-frequency current and those with continuous or low-frequency current is due, I have little doubt, to the first being a displacement or condenser current, as has been previously suggested. If this theory is correct, it might be that the absence of sensation is due to the fact that little or no current actually passes through the skin, the latter being merely charged at each alternation of the current, though I would hesitate to say that this would account for the whole difference. Inside the skin the same thing occurs, with the difference that the cellular structure forms a less perfect condenser and has more leakage between different parts than there is through the skin surface; also there is considerable hysteresis or friction due to the molecular movement incidental to the high-frequency charge. The internal heating that occurs is thus due more to hysteresis than to the actual passage of a current, and it is important to bear in mind the difference between the two, as this indicates a means of controlling to some extent the position where the heating will be most pronounced, since the lower the frequency the greater will be the heating effect on the parts of high resistance. Another point is that the high-frequency current being largely a condenser or displacement current the actual power supplied will be less than appears to be the case. The 1,000 volts and 400 milliamperes mentioned in the paper will probably represent more like 200 watts than 400 watts. In connection with the short bibliography given at the end of the paper it might be mentioned that in 1910 Dr. Eugene Doyen communicated to the International Congress of Physiotherapy a report of his treatment of cancer by means of electrically produced heat.*

* *Electrical World*, 1910, vol. 55, p. 935.

Regarding Dr. Knox's paper, the 7-inch spark referred to would correspond to about 60,000 volts between rough surfaces; but as it occurs between smooth balls, and the pressure is maintained for only a small fraction of a second, it corresponds probably to a considerably higher figure. As a first approximation, 100,000 volts might be near enough, and 200 milliamperes at this pressure represents 20 k.v.a. This for 1/200th of a second gives 1·66 volt-ampere-minutes. If the power factor were unity this would represent 73 ft.-lb., but as the power factor is likely to be considerably under unity probably 50 ft.-lb. is a closer approximation to the value of the impulse given to the tube terminals under a high-power single impulse. Most of this is lost in the tube in heat and non-useful rays, and even the rays that finally reach the photographic plate are not all utilized in the chemical action that produces the image. The field for improvement here is obvious. Regarding the question whether the induction coil or the transformer is the better for single-impulse work, I would say that whilst in my opinion neither of these forms is well adapted for the purpose, the transformer is likely to be the more efficient of the two. A better arrangement would combine some of the characteristics of each, this being virtually a transformer with a comparatively short air-gap in the magnetic circuit. The great fault of the induction coil is that it discharges too quickly, and with a peaked discharge, so that the discharge is only at its most effective value during a fraction of the extremely short period during which it lasts. Also, a powerful current is needed to energize the coil. The transformer as used also requires a powerful current, since this does not store energy to any appreciable extent, but it is still capable of giving a more suitable discharge for the efficient working of the tube. What is wanted to secure the maximum effect is to apply across the tube terminals for a period of 1/40th of a second to 1/20th of a second (not a fractional part of 1/200th of a second) approximately the maximum pressure the tube will stand. This is short enough to give sharp pictures with any ordinary degree of movement of the object being radiographed, and is long enough to give a good picture without excessive strain on the tube. With the arrangement employing a nearly closed magnetic circuit, it would be possible to get this, using only a small current gradually applied to energize the magnetic circuit so as to get no reverse-current discharge in the tube (I believe it is possible to get a vacuum tube "valve" to prevent the passage of a reverse current even if present), a quick break giving the working discharge to the tube. In addition to using only a small working current, this arrangement would have the advantage of always giving the same discharge for a given current applied to the primary, which would be readily measured. Suitably proportioned and manipulated I think about seven or eight times the power now realized with most of the present arrangements could be obtained using tubes as at present available. As the tubes may be increased in capacity much higher powers are possible, and progress at a fairly rapid rate should be possible, since the penetration of the rays increases at a very much higher rate than the applied power. Provided that tubes can be suitably developed I see no prospect of an early limitation to the means of applying power to them. In fact, if 1,000 times the present-day power were required, I think this could be done by a discharge of less than 500 kw., but taking only a small fraction of this power from the supply mains for a few seconds. The weight of such apparatus, so far as I can estimate with the very meagre data at present available, would be about 5 tons, and the cost probably about £700. Both the weight and the cost would be reduced with the improvement of insulating material, so that even this apparently extreme power is by no means outside the bounds of commercial practicability.

Sir James Mackenzie Davidson: I am particularly interested, as all medical men are, in this flash radiography. The suggestion made by Dr. Knox that electrical engineers might help us to produce a more perfect apparatus is a most valuable one, and I hope they will do so. About 16 years ago I tried an experiment which I think might be worth mentioning, as it might possibly form a basis for a more perfect apparatus than exists at present. At that time I was interested in flash photography from the merely physical point of view. I employed a 10-inch App's coil for the experiment, with 24 volts on the primary (from accumulators). The condenser was cut out, and in the primary circuit was interposed a wire supported by an insulated frame, stretched across the nozzle of a small revolver. The current was turned on, which fully saturated the primary, and then the revolver was fired. The wire of course being broken very suddenly by the bullet, the gases blew out the arc formed at the break. So by this means a very perfect and sudden break took place, which produced a most vivid flash in the X-ray tube attached to the secondary. When the revolver was placed against a photographic plate (protected from light in the usual light-tight bags) about 6 inches from the X-ray tube, an X-ray photograph was obtained of the bullet in its flight and of the broken wire. The duration of the flash appeared to me to be about 1/2,000th of a second. It seems to me that electrical engineers might make use of some arrangement of this type, using a very powerful coil and no condenser; such an apparatus might prove to be an extremely satisfactory flash X-ray apparatus. If the firing of the revolver were an objection, an air gun, or a compressed carbonic gas gun could be utilized instead to break the wire.

Captain J. Coxon (*communicated*): On page 349, paragraph 2, Dr. Cumberbatch refers to the heating of the deep-lying tissues as well as those on the surface by high-frequency currents, and the measurement of the temperature by thermometer. These surface temperatures may, I suggest, be somewhat misleading, as it is well known that high-frequency currents do not travel through a conductor at uniform densities but tend to confine themselves to the surface as the frequency is increased. It is suggested that the interior heating may still be mainly by conduction from the exterior parts and tissues, through which the current is principally passing and is therefore not uniform throughout. In paragraph 5 the author states that a frequency of 100,000 per second or more is necessary,

and produces this from a D'Arsonval transformer excited from a transformer supplied with alternating current at 100 periods per second. He assumes that high-frequency current is passing for 1/50,000th of a second per half period. As each half period in the primary circuit produces a spark and an oscillatory discharge of the condensers, the damped train of oscillations will produce high-frequency current for a period depending upon the damping or decrement of the high-frequency circuit. Hence the author's method of arriving at the time the high-frequency current is passing appears to be too low. He also terminates this paragraph by indicating that sustained oscillatory currents are desirable, and he describes a generating set the development of which is on a parallel with the development of the wireless transmitter, i.e. the use of a quenched spark gap. I suggest that he should go a step further and experiment with a continuous wave generator, such as an oscillation valve or small Poulsen arc generator, which would give continuous undamped high-frequency currents.

Dr. F. Hernaman-Johnson (*communicated*): Dr. Cumberbatch has given a very interesting résumé of the theoretical and practical sides of high-frequency and diathermy currents. Regarding high-frequency, it is commonly held, as the author has said, that during a half-hour sitting with ordinary high-frequency applications, the discharge actually passes through the body only for a few seconds. It is difficult here to reconcile the clinical effects with this theory, as very definite phenomena, such as the lowering of blood pressure and the increase of metabolic processes, occur. I refer, of course, to what is usually known as general high-frequency treatment on a condenser couch. Diathermy may be used to produce similar results. The ordinary high-frequency currents admittedly generate but little heat, and although they produce neither sensation, muscular contraction, nor obvious chemical effect, their general action upon the body may fairly be described as electrical, i.e., if not carried to excess, they stimulate all physiological processes and act as a tonic. When, therefore, we see beneficial local or general effects resulting from the medical use of diathermy—as, for instance, in treating a rheumatic joint—we should not be in too great a hurry to put down all the results to the action of heat alone, even though it can be demonstrated that this heat permeates all the tissues between the electrodes. To put the matter in terms of dynamics, the living matter between the electrodes has impressed on it that form of motion known as heat, and this is in itself sufficient to produce changes of metabolism; but it is probable that other and more subtle modes of motion, which we vaguely term "electrical," are also imparted and contribute to the sum of the observed effects. So far at least as the non-surgical use of diathermy is concerned, I think it wise at least to keep in mind the possibility that the most obvious property of this current may not constitute its only, or even its chief, value.

With regard to Dr. Knox's paper, I have been much interested by his photographic experiments with the metronome with a view to determining the time occupied by the "single flash." Assuming the arc described by the weight of the metronome to be about 6 inches in length, and the time taken to traverse it half a second, it is obvious that the discharge in the case of one of his installations fairly deserves the name "instantaneous." This is shown by the comparative sharpness of the image. It will be noted that this refers to the case in which only the "break" current is used. But with the Siemens instrument, where both the current at "break" and that at "make" is employed, two distinct images are seen, separated by a small interval. I suggest that these represent the "break" image and the "make" image—the latter being the less intense. The ratio of the space between the images to the total length of the arc would enable us to determine the additional time taken by the "double flash" as opposed to the "single flash" instrument. It is evident, therefore, that if this explanation of the two images be correct, the increased intensity due to the two flashes is purchased at the cost of a considerable lengthening of the exposure. But the time fractions dealt with are so minute that this may not matter in practice. For example, the excursion of the heart's outline is probably only about one-tenth that of the metronome weight, and thus the sharpness of the image would scarcely be affected.

Mr. N. E. Luboshey (*communicated*): I should like to make a few remarks from the photographic side of X-ray work. What Dr. Knox has told us and the slides that he has shown prove that the standardization of radiographic work is not so far off as many workers seem to think at the moment. By the use of suitable tubes we have seen how easily and with a fair amount of certainty the effective light on a photographic plate can be measured, and if we sum up from a photographic point of view, I can only say that it has been clearly proved by Dr. Knox's paper that what we want is more light. We can get it now, as Dr. Knox has shown, at a certain distance; but he has also shown us definitely that this distance is not satisfactory for many cases, and we are therefore looking for more. Excellent radiographs have already been produced by time exposures and varying the distances, but Dr. Knox seems to be very much in favour of instantaneous radiography and has given very convincing reasons for taking this view, proving that his difficulty in getting all he wants is the lack of light; in other words, it is exactly the same trouble that we have in photography. We cannot take instantaneous photographs unless we have the necessary amount of light to give a good image at a fraction of a second exposure. The same thing applies to X-ray tubes; if we can use tubes that will give us more light, and if we can control this light, even to the extent that we can already control the Coolidge tube, we shall be able to realize a great deal indeed. We have seen clearly that, by giving repeated instantaneous flashes, we can get the amount of light we want. We have also seen that by reducing the distance we get enough light, and we have seen that by increasing or diminishing the spark-gap we get variations of light which can be distinctly measured. The whole of these experiments definitely show that, given enough light to do at 6-ft. distance from the object what we get now at 1 or 2 feet, we can get single-flash exposures which will cover a very much

wider ground of work and possibly most of the work that is required just now—all instantaneous. It is for this reason I consider that when these points are made clear to electrical engineers, we may reasonably hope, as Dr. Knox has shown, that with their co-operation we shall arrive at what is wanted, namely, sufficient light at such a distance that the image will not be distorted, retain almost its normal size, the light be less dangerous to the person exposed under it, and all the advantages of the usual instantaneous photography in taking a subject in movement, and in this case, of course, the movement of the heart, for example, or stomach, etc., would be photographed with much greater precision and ease than is done at present. Of course the advantage of instantaneous child radiography is so obvious that I need not enlarge upon this. There is a further point with which I, at this stage of radiography, cannot see my way to agree exactly, but to which, nevertheless, a good many radiographers attach a great weight, namely, the work could be carried out without an intensifying screen, which at present is almost indispensable for instantaneous radiography. So, if we can have a greater output of light, more efficient control of it, better switches and all those mechanical contrivances which will make the work still more certain than it is at present, this will give us an image which can be standardized; and it will remain for the photographers to standardize the method of developing that image on the plate or film in such a way that a very much greater percentage of excellent work in radiography will be the result. Perhaps it will not be too much if I add that should a similar Joint Meeting be held, photographers might be included.

Mr. H. Rocky (*communicated*): Dr. Cumberbatch has shown in his paper to what excellent use alternating current of high frequency may be applied, but he does not definitely mention if the apparatus at present in use leaves openings for further improvements. This induces me to make a few remarks regarding my own experience in this matter from an engineering point of view. Diathermy apparatus have been constructed in various forms and with various types of spark-gap, as mentioned by Dr. Cumberbatch. The most essential part of all the diathermy apparatus is the spark-gap, and upon this part of the apparatus engineers will consequently have to concentrate in order to find the most efficient and yet the simplest and handiest form. Past experience teaches us that improvements are still needed and finality has not yet been reached. The second factor for consideration is the voltage of the high-frequency current. In view of the fact that a most important use for the apparatus has been found in surgery (in which case an electrode at the end of an insulated wire is introduced into the bladder through a metal instrument having a narrow channel of about 2 mm. diameter) it is evident that the factor of safety will be increased if the voltage is kept as low as possible, expecially as this can be done without reducing the efficiency of the apparatus. Apparatus in which the secondary pressure of the step-up transformer is only 1,000 to 1,200 volts have proved to be highly efficient for all purposes. The use of diathermy in surgery has to my knowledge produced a demand for a small portable apparatus which may be used from an electrical supply without the need of special cables or motor transformers, as required for the larger universal apparatus as shown by Dr. Cumberbatch and which approximately requires $1\frac{1}{2}$ to 2 kw. of alternating current. This latter portable apparatus has been obtainable for some time and consumes from 350 to 600 watts and may therefore be connected to any wall plug. It offers special opportunities to engineers for improvements, as a really efficient and portable apparatus of this kind will be of great value for operative work and for local applications. I hope the above remarks may stimulate further discussions by medical men using the various kinds of diathermy apparatus in order that the failings of the various types in practical use may be discovered and improvements suggested.

Dr. Knox has put before us problems which without doubt are of the greatest importance. Prior to the advent of the Coolidge tube and the tungsten target tubes the power of the apparatus available was greater than the capacity of the tubes would admit to be used without too great a wastage of costly tubes. This has fortunately changed and we can now seriously consider the possibility of sending impulses of more than 200 milliamperes through X-ray tubes. It is only natural that engineers in this country have up to now abstained from investing large sums of money in the manufacture of apparatus for which the market was so limited as that for single-flash X-ray coils. Dr. Knox opens an exceedingly gratifying prospect by pointing out that the need of this powerful apparatus has now become an imperative necessity and his appeal to the electrical engineer will not be in vain.

Mr. J. E. Taylor (*communicated*): The high-frequency apparatus described by Dr. Cumberbatch is very similar in type and operation to some forms of transmitting apparatus for wireless telegraphy, and experience gained with the latter can be usefully applied to that under discussion. Attention may, perhaps, be usefully directed to the exact interpretation of the ammeter readings as affording an indication of the degree of heat developed in the tissues to which the high-frequency current is applied. The high-frequency ammeter is of course referred to. In most cases the readings will no doubt be a reliable guide to the degree of heat developed, but the fact should not be lost sight of that in the form of apparatus described the high-frequency current is not of the uniformly sustained type, but consists of a succession of "bursts" of energy with comparatively long intervals of quiescence. The bursts of energy correspond to the separate discharges of the condenser in the high-frequency generating circuit, that is, with the "spark frequency" used. Each burst of energy developed in the tissues takes the form of a train of electrical oscillations of limited duration. The ammeter averages these oscillations over the time including the interval of quiescence, but tells us nothing of the strength of an individual train. That requires to be deduced by taking the spark frequency into consideration. If the amount of tissue to be heated is such that the heating process is a gradual one, each train determines a certain accretion of temperature, the final temperature being thus arrived at

by stages. But if it were desired to heat up a thin filament or very small mass of tissue the temperature developed momentarily during one train might be dangerously in excess of the mean. This is probably important from the medical point of view. To guard against such effects the spark frequency should be of a high order. Preferably, indeed, a generator of sustained high-frequency current such as the oscillating arc or the ionic valve oscillator might be used. The ammeter readings would then be a sure guide. I do not feel assured that Dr. Cumberbatch fully realizes the intermittent nature of the high-frequency current in the apparatus he describes, as the spark frequency is not stated. It is not safe to assume that the spark frequency is double the periodicity of the alternating-current supply, since multiple discharges will probably be occurring at the spark-gap. The overall efficiency of apparatus of the kind described is probably very low. That is the heat energy developed in the tissues is probably small compared with the electrical energy taken from the source of power. This in itself is not very serious, having in view the medical results attained, but the surplus energy has to be released somewhere in the apparatus and is liable to cause trouble at the point of release. This occurs mostly in the spark-gap, where it develops intense heating effects and is the main cause of spark-gap troubles. The development of a suitable form of generator of continuous oscillations would appear to offer the best solution of these difficulties. There may be some field of utility in medical work for electrodeless heating methods and it is not unlikely that a certain amount of heat could be developed in tissues by using a sufficiently intense high-frequency magnetic field to induce high-frequency eddy currents in them. Or again sufficiently intense electric fields alternating at a very high frequency may produce heat by dielectric losses in the tissues, especially if the field be formed in an oil bath in which the tissue is placed. Until we know more of the order of high-frequency conductivity in tissues, however, it is not possible to be certain that useful results could be obtained on either of these plans, and it is certain that at very high frequencies the skin effect exhibited by conductors would place a limitation on the scope. As mentioned by Dr. Worrall, the term "endothermy" would appear to be more appropriate to the methods described in the paper, the process involved being akin to that concerned in the production of endothermic flames.

Dr. Knox's interesting discourse on single-impulse radiography certainly emphasizes the desirability of improving the efficiency of apparatus for exciting X-ray tubes. Apparently it is highly desirable to be able to pass as large an amount of high-tension direct current as possible through the tube in a very short time and so produce an intense flash of X-rays of suitable penetrative power. In my view the ordinary spark coil or even high-tension transformer is not at all ideal for producing this result. The type of single discharge given by a spark coil is not such as to produce the largest possible burst of electric energy at a fixed voltage. Such discharges are always peaky; that is to say, they are very far from the flat-topped wave form that represents the ideal to be aimed at. This peakiness is inherent to coil or transformer methods, and is no doubt accentuated by effects occurring at the primary interrupter at the moment of current break, and is added to by vagaries in the magnetic behaviour of the iron core. If such peaky discharges could be replaced by flat-topped discharges with very abrupt rise and cessation, far larger energy rushes through the tube could be obtained in the same short interval of time. In other words, what is apparently required is a very high-tension direct current of uniform voltage with means of applying to it the tube for definite short intervals of time. In my opinion this is not beyond practical attainment. Both in electric heating treatment and radiography there is undoubtedly a wide field for further development and experiment. The rate of progress will, I venture to think, be much hastened by proper co-operation between the medical and electrical professions.

Dr. E. P. Cumberbatch (*communicated reply*): In his criticism of the term "diathermy" it appears that Dr. Worrall assigns to it a meaning different from that which I understand it to convey. The prefix "dia" indicates that the heating is "through," and it refers to the "distribution" of the heat and not necessarily to the way in which it is applied or generated. If a piece of meat is cooked through and through by applying heat to its surface the heat is gradually distributed through it by conduction. If it is traversed by a strong electric current it will be quickly cooked through because heat is generated throughout it as the current overcomes its resistance. In both cases heat is distributed through the beef; in both, diathermy has been performed; but it has been brought about by different methods in the two cases. I think that other workers use the term "diathermy" in the same sense in reference to its distribution. The word was devised to express the heating-through of tissues *by the electric current*, so when we speak of medical treatment by diathermy it is understood that the electric current is used for the purpose. Some workers use the term "thermo-penetration." It is, however, less accurate; it would indicate rather the distribution of heat by conduction. Others speak of "transthermy." Both transthermy and thermo-penetration are hybrid terms and inelegant. The word "endothermy" suggested by Dr. Worrall is open to criticism. The heat is developed not only *in* the tissues but *on* them as well. The electric current produces endothermy and epithermy, i.e. diathermy. The term "diathermy" has been generally adopted and I do not see that it should be discontinued.

Dr. Worrall also criticizes my statement that "this method of applying heat differs from all others in that it causes a rise of temperature of deep-lying tissues as well as those on the surface." I see no reason for altering it, as I am speaking of the application of heat *for medical purposes to living tissues permeated with circulating fluids*. The comparison of the application of heat for this purpose with the cooking of dead tissue which has no circulating fluid is a false analogy. The skin will not tolerate more than a few degrees rise of temperature, and the heat would have to be applied for a far greater length of time than is possible in clinical

practice before it penetrated any depth. Not only would the tissues conduct the heat badly, but the circulating fluid would dissipate it. Therefore, heat which is applied from without and distributed by conduction produces, in clinical practice, only surface heating or "epithermy." Further, if it is desired actually to destroy abnormal tissues, such as a cancerous growth, the latter would be roasted by applying heat from without, but the process would take a considerable time and it would be very difficult to restrict the heat to the part desired. For clinical purposes, it may be said with truth that the use of the electric current for heating the tissues differs from other methods in that it causes a rise of temperature of the deep-lying as well as the superficial tissues, and that the method of heating by means of a hot body placed on or near the skin raises the temperature of the surface only.

When I read the paper I refrained from making more than the briefest reference to the medical and surgical uses of diathermy. The latter has been extensively used at St. Bartholomew's Hospital for the treatment of inoperable malignant growths. Cancers of the skin, mouth, throat, tongue, œsophagus, uterus, bladder, and rectum have been treated. In most cases there has been a relief of symptoms and in many a prolongation of life. I treated a case of inoperable cancer of the tongue, and for a year there was no sign of recurrence. The patient died ultimately nearly two years after the diathermy, from a secondary growth, but the tongue remained free till the end. In the treatment of innocent growths the results are most gratifying. In cases of papilloma of the bladder it appears to be the treatment *par excellence*.

With regard to the non-surgical uses of diathermy, it may be said that more work must be done before this method of treatment can be assigned the place which it will ultimately occupy in therapeutics. Pain due to neuritis can usually be relieved, in some cases temporarily, in others permanently. Maladies due to infection by the gonococcus seem to be particularly suitable for treatment by diathermy. Arterio-sclerosis and the symptoms which arise from it are often very satisfactorily treated by diathermy.

Mr. Burnand suggests that the absence of sensation accompanying the passage of the high-frequency current is due to the fact that the latter is a displacement or condenser current and that little or none of it passes through the skin. There is no doubt at all that heat is generated in the skin and under it, and in the deeper parts. A thermometer has been placed within the brain of a dog and electrodes applied to the exterior of the skull on opposite sides. On connecting the electrodes to a source of current the thermometer showed a rise of temperature of 1 degree C. after the current had passed for 10 minutes. I am much interested to hear that the heat developed in the tissues is due to hystersis rather than to actual passage of the current.

Captain Coxon says that the high-frequency currents do not flow through a conductor at uniform densities, but tend to confine themselves to the surface as the frequency is increased. Is this true when the conductor is composed of the body tissues permeated by fluids containing ions? The experiment on the dog's brain which I have just mentioned shows that heat is developed in the depth of the conductor. As Mr. Burnand has said, the development of heat in the interior of the brain may be due to hysteresis rather than the passage of the current. For medical purposes, however, what is needed is the elevation of the temperature of the deep-lying parts. A thermo-couple thermometer will also show the rise of temperature in the depths of the tissues. I feel convinced that the interior heating is not by conduction; the rise of temperature takes place far more quickly than would be the case if the heat had to spread by simple conduction.

Mr. Rocky is quite right in stating that a small portable diathermy apparatus is needed—one which can be connected to a wall plug. The forms of apparatus which I have used up to the present time are almost too heavy for transport, especially if alternating current is not available and a motor transformer is required. As he says, the spark-gap is the most essential part of the apparatus, and further improvements of this part are needed.

Mr. Taylor draws attention to the method of measuring the high-frequency current by means of the hot-wire ammeter. When the current is used for surgical purposes, viz. the destruction of new growths, it is allowed to pass for only a few seconds and it is doubtful then whether the ammeter gives an accurate register of the strength of the current. Personally, when I am using the current for surgical purposes, I do not pay attention to the reading of the ammeter but rather regulate the strength of the current according to the effect it is producing on the tissue. I do not know the spark frequency in the apparatus exhibited, but I regard it as considerably higher than double the periodicity of the alternating-current supply. An apparatus which would produce an even rise of temperature to a known degree and an even distribution through any part of the body would be of great value for the treatment of extensive malignant growths, because the cells of the latter succumb to a temperature which is slightly lower than that which will kill healthy tissue. I cordially endorse Mr. Taylor's belief that the rate of progress in radiography and treatment by electric heating will be much hastened by proper co-operation between the medical and electrical professions.

Dr. R. Knox (*communicated reply*): Dr. Metcalfe's remarks are particularly interesting to me, and I am pleased to find that we are in agreement on all the main points. His observations on heart radiography show how valuable the single-flash exposure is in this branch of our work; already we are able to show the varying condition of cardiac contraction and relaxation (systole and diastole of the heart), and in a number of the plates obtained, intermediate phases can also be recorded. I am at present engaged in an analysis of 1,000 plates of single-impulse exposures of the thorax, and am paying particular attention to the alteration in the shape and position of the heart. I mention this to indicate how far we have reached with the present apparatus, and to indicate how much more valuable our observations would be if we could work at a greater distance between the anticathode and

the plate. I should like to point out also that the more powerful apparatus would enable us to dispense with the intensifying screen, which I am pleased to see Dr. Metcalfe agrees would be a desirable result to aim at. I also have tried the film between two screens; the method certainly shortens the exposure, or rather gives an intensified effect for the same exposure. But I would infinitely prefer to work without the intensifying screen.

Mr. Burnand makes some valuable suggestions. 200 milliamperes is about the maximum output obtained from the single-impulse exposure so far as I have been able to ascertain. It would be helpful if we could have designed for use in X-ray departments a reliable instrument for estimating the current passing in the tube circuit. I agree that at present we have not got the ideal arrangement of apparatus for this class of work. In the coil outfit particularly is this noticeable. I think the designers have lost some of the power by trying to make the apparatus a universal one. It seems to me that if a coil has to be used, it and the auxiliary apparatus attached to it should be designed for one purpose only. Then perhaps we might get a greater efficiency. Valve tubes are a constant source of worry to the radiographer, so if we can have apparatus which does not require a valve tube the execution of our work will be more easily accomplished. A valve tube requires nearly as much care as the X-ray tube in ordinary work. We would be content to work with a fraction of 1,000 times the present-day power, so I can see a prospect of soon obtaining the more powerful apparatus we require at a fraction of £700. But if the latter figure were the minimum and it could be proved that the apparatus were necessary, I have no doubt that in time our committees would consent to meet the cost, but I am certain that thoroughly efficient apparatus could be turned out at a much smaller figure.

Dr Hernaman-Johnson suggests the likely explanation of the double shadow. This has been dealt with in an addition to the paper. I agree with him that the fraction of time between the make and the break is of no great importance, but if it is proved that the double shadow is due to make and break, then we are not dealing with a single-impulse exposure and I think a better method should be adopted.

Sir James Mackenzie Davidson's description of a method of interrupting the primary circuit, and so obtaining a flash exposure through the tube, is interesting and serves to show that very early in the development of radiography the methods now in use were known and were not developed in practice because of the small output from the coils of these days. One 2,000th of a second appears to be an extreme estimate of the duration of the exposure, but I do not doubt that Sir James with his customary care took steps to estimate it accurately.

Mr. Luboshey is very encouraging in regard to the photographic side of the work. I believe with him that it will soon be possible to standardize the X-ray plate, its development, and later the exposure necessary to produce standard results. That will, however, necessitate standardization of all the apparatus used. When that is accomplished I shall feel that we have made a most important advance in radiographic technique.

I am pleased to think that Mr. Rocky regards the future hopefully from the point of view of the manufacturing firms. I can assure him that if they will only give us the apparatus we require, the result from a purely business point of view will be equally gratifying.

Mr. Taylor is most helpful in his suggestions. He agrees that the ordinary spark coil or even the transformer is not ideal for our purpose. I shall be greatly interested in watching the development of the new design his remarks lead me to look for. I infer that the new type of machine will not require valve tubes for the rectification of inverse current. In my remarks on valve tubes I refer to the variable character of their action. I might have said that at present valve tubes are difficult to obtain, and because of their being required in other branches of electrical work this difficulty may increase.

I understand that the Kenotron referred to by Mr. Darnell in a paper read before the Röntgen Society is a most efficient rectifier of inverse radiation. I believe that this piece of apparatus may in the future be used to displace the valve tube of the present time, and that when used in conjunction with a simple closed-circuit transformer the ideal apparatus for exciting the X-ray tube will be found. In this combination no rotating parts will be necessary, the Kenotron cutting out half of the wave from the transformer; thus a perfect undirectional current can be obtained. The Kenotron can at the present time carry up to 100 milliamperes; and this may be greatly exceeded in future developments of the combination.

I should like in conclusion to express my thanks to the Institution for giving me the opportunity of placing before them a few of the problems which we of the medical profession have to deal with when we venture into the domains of electricity. We are sadly lacking in the technical side of electricity and are therefore almost wholly dependent upon the electrical engineer for the supply of efficient apparatus for our purpose. It is therefore particularly appropriate that we should meet from time to time in our laboratories for plain heart to heart talks in order that we may be in a position to obtain the best from all. The development of electricity in the service of medicine is capable of great expansion, and if we can get the collaboration of electrical engineers, manufacturers, and medical men, I feel sure that we can set up in this country a standard equal to that of any other country. Standardization all along the line should be our watchword, and I hope I have been able to put clearly before electrical engineers the urgent need for such standardization.

THE OVERSEAS DISTRIBUTION OF ENGINEERING APPLIANCES.

By Leonard Andrews, Member.

(*Paper first received* 23 *January, and in final form* 22 *March*, 1918; *read before* The Institution, 18 *April*, 1918.)

No apology is thought to be necessary for presenting to the Institution a paper on a subject that is at the present time of very great national importance, for it is generally agreed that the continuance of Great Britain's present industrial supremacy is mainly dependent upon the standard of efficiency reached and maintained by the engineering profession and trades. Not only does the mere monetary value of engineering products in itself represent a considerable portion of this country's total export trade, but a far more potent factor in the commerce of the Empire is the indirect influence of engineering exports upon all other industries. Every modern industry is dependent for its existence upon a great variety of specialized engineering appliances. Furthermore, every big engineering achievement invariably leads to the establishment and development of numerous other industries. It may be that the construction of a large hydro-electric installation or the tapping of a natural gas field provides the locality with cheap power, or that the opening up of a railway, the cutting of a canal, or the building of a bridge facilitates transport, or again, that the damming of a river irrigates and renders fertile a tract of country which was previously a barren waste. The engineering work frequently proves to be the pioneer of a new settlement, which in time contributes to the wealth of the world in a measure far in excess of the most sanguine anticipations of the original promoters.

Experience has shown that the country which carries out any original engineering work abroad usually secures the bulk of the subsequent trade of that country, created by the industries thus established. The British Empire owes its present industrial position to the fact that for many generations this country has been the recognized engineering workshop of the world, though in recent years Germany has made special efforts to undermine Great Britain's long-established lead in this respect.

It is an axiom of political economy that no one nation can attain a supremacy over other nations in all industries since interchange of products between nations is the foundation of international trade.

The community that is in a position to select the industries likely to be of the greatest benefit to the commonwealth, should obviously devote first attention to those industries which—

(*a*) in times of peace would contribute most to the advancement of other industries;

(*b*) in the event of war could be most fully utilized for offensive and defensive purposes.

There can be little doubt that the engineering industries meet the above requirements more fully than any other does. It is therefore a matter of the greatest national importance that British engineering industries should be fostered and developed to the fullest possible extent, and that, if necessary, State funds or credit should be applied to this purpose.

All who have visited engineering works in other countries—particularly in the United States of America and in Germany—must have been impressed by the fact that, as pure engineering craftsmen, British artisans can more than hold their own with any and all competitors, but that as an economic distributor this country has much to learn both from the United States and from Germany.

That Great Britain's superiority as a producer of engineering appliances is fully recognized by her competitors, is shown by the well-known German writer, Friedrich Naumann, who, in his "Mittel-Europa," published in the autumn of 1915, writes:—"In industry, machinery and craftsmanship the English were, and are, our superiors." *

It would almost appear that both Germany and America—having recognized the strength of this country's position as a producer—decided to concentrate their attention upon improving distribution and have thereby attained an exceedingly high state of efficiency in that particular respect.

The effect of this upon British overseas trade has been so great as to have become a matter for general comment in all markets; so much so, that H.M. Trade Commissioner for Canada was only voicing the opinions of practically all overseas buyers when he expressed the view at a meeting of the Institution of Civil Engineers last session that if Germany had not declared war now, in effect, she would have swallowed us up in less than 10 years.†

That mere efficiency of production is, comparatively, of little value unless combined with efficiency of distribution is well exemplified by the history of the electrical industry.

The many and varied problems relating to the engineering and commercial distribution of electricity have been thoroughly discussed at various meetings of the Institution, and there is probably no other industry in which the question of efficient distribution has been treated as an exact science to a greater extent than in the electrical. The author, therefore, ventures to suggest that, as many of the problems associated with

* *Round Table*, June 1916, p. 427.

† Discussion on Mr. E. Crammond's lecture before the Institution of Civil Engineers (see *Times Engineering Supplement*, 30 March, 1917).

overseas trade are so closely analogous to the difficulties which have been successfully overcome in distributing electrical energy, the past experiences of electrical engineers should enable them to render valuable assistance to the executive officers of the various organizations which at the present time are devoting so much attention to the improvement of British foreign trade.

The attitude of those manufacturers who cater only for trade f.o.r. their own works, may be compared with that of a power-plant superintendent who only concerns himself with efficient production at the main busbars and assumes that all questions relating to distribution are beyond his province, and who, moreover, considers that a reliable, low-priced supply should be sufficient inducement to the consumer to make his own arrangements for the distribution and application of the service outside the generating station.

It is quite conceivable that if the supply of electrical energy had in the past been conducted exclusively upon such lines, it would have been exceedingly difficult at this time to have persuaded power-supply companies that by incurring distributing charges amounting to more than 100 per cent of the cost of production at the busbars, electric power could be delivered and sold at a lower price than when no distributing charges were incurred by the supplier. It would, in fact, have been quite impossible to have foreseen or calculated the effect of those many factors associated with efficient distribution which experience has shown to have had such a material bearing upon the cost of production.

It is just as necessary, in connection with international trade as in military strategy, to study the tactics of the enemy, and it may therefore be useful at this point to consider briefly upon what basis German industrial developments have made such great strides during recent years.

Naumann, in his "Mittel-Europa" previously referred to, continues:—

"In the last 20 years our German industries have assumed a wholly new appearance. Whilst growing they have grown into one another. Through employers' associations, buying arrangements, agreements as to prices and selling areas, a complex system of mutual attachments and dependencies has come into being. A stranger would no doubt find all this too intricate to unravel, but it has grown up bit by bit to meet one need after another, and has quietly, in the course of one generation, carried over the old-fashioned individual employer, even if he originally set his face against it, into an ordered industrial community-life. . . . From personal motives he becomes a member of impersonal institutions and works for them as for himself. This dovetailing of the individual-self into the community-self is what we are pre-eminently able to achieve. . . ."

What Germany claims to have achieved in 20 years, the British Empire has accomplished in as many months. The conversion or aggregation of many thousands of industrial factories in all parts of the Empire into one huge arsenal for the manufacture of war material is, without question, the most remarkable example of the dovetailing, or sinking, of the individual-self into the community-self that could be imagined.

The Effect of Supply and Demand upon Competition.

The absence of competition between engineering manufacturers since the outbreak of war has been mainly, if not entirely, due to the fact that the demand for war material has been more than sufficient to keep all of the old established works, and many new ones, fully employed. It has indeed been an illustration of the fact that competition is entirely controlled by the law of supply and demand. It is usual, when referring to this law, to assume that demand is a generative factor and that supply must, of necessity, accommodate itself to such demand as may happen to exist. It has, however, been demonstrated by electric power-supply undertakings that demand can be created to an almost unlimited extent. Therefore, to reduce or eliminate excessive competition, demand should be developed or increased to balance available sources of supply.

It is the recognized privilege of engineers to devote their lives to the work of extending the benefits of modern civilization to all parts of the globe—some as producers and others as distributors. There are millions of British subjects working in overseas territories for the benefit of those who prefer to stay at home, who are just as appreciative of, and equally entitled to enjoy, the comforts of modern civilization as those who are already benefiting by these conveniences.

Many British farmers on remote prairie farms in, say, Western Canada, are to-day able to live in well-built houses fitted with electric light, long-distance telephones, innumerable labour-saving appliances and modern sanitary arrangements. They have their motor cars, and in many cases they can read at their breakfast tables the news which appeared in the London papers the evening before.

For these, and other benefits, the farmer is indebted to the engineer—or rather, engineers have repaid by these means some of the debt they owe to the overseas farmer for the benefits they enjoy as the result of the latter's work. It is, however, only the merest fringe of the work that has been touched so far. For every overseas British subject who is able to secure these advantages there are thousands to whom they are at present not available. Hence, the scope for developing a demand for modern engineering appliances in this field alone is practically unlimited.

During the war many Englishmen will have learnt, from their overseas comrades at the Front, something of the conditions and scope for development in the new lands from which the latter have come at the call of the Mother Country, and they in turn will have seen enough of this country's products to have acquired a desire to participate in them more fully than they have done in the past.

One of the author's old Canadian assistants—now at the Front—in a recent letter to him writes:—

"When the war ends, about 250,000 Canadians will exist who will have a knowledge of England undreamt of before, and the Englishman who takes advantage of this for English manufacturers is going to do business on a large and very satisfactory scale."

Bulk Supply.

The economies effected by combining under one management a very large capacity of generating or producing plant have been demonstrated by the growth of large central stations and the gradual absorption or closing down of small individual plants.

The principles of bulk supply have been applied extensively in the United States and in Germany (also to a limited extent in this country) to the production and distribution of many products other than electric power.

The principle on which these bulk-supply schemes is founded is economically sound, and they should therefore be to the advantage of the community, since they tend to eliminate a large amount of the wasted energy at present expended upon useless competition between individual firms. This wasted energy is, of course, eventually paid for by the consumer.

It is noteworthy that the entire absence of competition between engineering manufacturers at the present time has not tended to increase the cost of production of war material, but has, on the other hand, greatly reduced such costs.

It will also be remembered that it was at one time anticipated that the granting of Provisional Orders to public electric supply undertakings might result in the creation of monopolies, with the consequent enforcing of exorbitant charges for electric power, and to guard against this danger a statutory maximum price was fixed in all cases. That this danger was more imaginary than real has been demonstrated by the fact that the actual rates charged by all electric supply undertakings are in every instance very much lower than the statutory price.

Long-distance Transmission Service.

It is the aim of the distributing engineer of every electric supply undertaking to maintain a good service even at those points most remote from the generating plant. In the early days of the industry the district served by each central station was densely populated and of comparatively small area; but, in course of time, the areas in which a supply was required became larger and less densely populated, thereby introducing entirely new problems of distribution. The problem of distributing engineering products is somewhat analogous. The United Kingdom as a distributing area for such products is a comparatively small and very dense district supplied by a large number of producing units situated in the most advantageous centres for short-distance service. The home market demand, or f.o.r. maker's works trade, for engineering appliances has been so great that British manufacturers have not experienced the necessity of combating those problems associated with distribution over a large and scattered area such as exist in the United States and in the overseas dominions. This circumstance has in a great measure contributed to the efficiency achieved by the United States in catering for overseas trade.

State or Private Enterprise Control.

The need for more perfect co-ordination between individual producers and between producers and distributors is now freely admitted. There are, however, considerable differences of opinion as to whether the centre of such co-ordination or control should be the State, or some private enterprise such as an association of manufacturers, or alternatively, some independent trading association.

The objection to private enterprise control is that any such undertaking must depend for its existence upon its profit-earning capacity, and where its aims in this direction conflict with the community interests —and there are bound to be many such cases—the latter will be liable to suffer.

On the other hand, the objections to State control are :—

(1) Such control would be liable to stultify individual effort, and since the entire fabric of existing British trade supremacy is the outcome of the work of individual firms and persons, it should be the first essential of any scheme of industrial reorganization that individual effort be maintained in a state of maximum efficiency at all costs.

(2) State control of any one trade or industry would entail the employment of a very large number of Government officials, who would generally know much less about the subject than the principals of the firms they would be endeavouring to control. Moreover, it may be anticipated that the efficient co-ordination of the work of such numerous Government officials would prove to be a greater problem than that of co-ordinating the work of the firms to be controlled.

It appears that actual production, at least, should be left to individual effort and should be entirely uncontrolled, though a closer co-operation between individual producers, such as is being effected by the various Trade Associations, and is the aim of the proposed Trade Parliaments, is undoubtedly to be desired. Some more direct control of distribution appears, however, to be necessary, but whether such control should be by the State or by private enterprise is still an open question. It is possible that some combination of State and private enterprise control may eventually prove to be the best solution.

The ideal to be aimed at is a subconscious co-ordination by indirect influence rather than the despotic mandatory control under defined rules and regulations usually inferred by reference to State control.

A symbolic illustration of such an ideal is afforded by the coupling in parallel of alternating-current generators where the sole controlling or co-ordinating influence is that resulting from the mere connection of the generators to common busbars. The generators may be of widely varying capacity and of greatly differing speeds. They may derive their power, some from steam engines and boilers, others from gas engines, and again others from oil engines, or even from motors and secondary batteries. So long, however, as they are all connected to the common busbars, each of the several units will supply its quota of power to the demand upon such busbars.

To carry this analogy a little further, let it be assumed that the successful paralleling of alternators had hitherto never been achieved, and that every generator in this country was directly connected to a group of consumers whose maximum demand at any time was equivalent to the full-load capacity of the generator. Even though the efficiency of such individual units was the maximum attainable, it is obvious that the inability to take advantage of the improved plant factor, the increased diversity factor, and other economies accruing from parallel running and bulk supply, would result in a combined fuel consumption at least 100 per cent greater than under existing conditions. Let it also be assumed that the individual-unit supply service described is suddenly called upon to meet the competition of a bulk-supply undertaking able to run its generators in parallel. It will be evident that notwithstanding the established connections or goodwill of the individual supply units, the bulk-supply plant will be working under such advantageous conditions that it will rapidly capture all of the demand.

The above analogy represents the conditions under which many British manufacturers, with their individual producing units, were working prior to the war, in competition with the co-ordinated or paralleled producing units of the United States and of Germany. The distributing networks of these foreign bulk-supply undertakings were being extended rapidly in every direction, but especially in British Overseas Dominions.

Government Postal Service and its Influence upon Trade.

Those who favour State organization of distribution can point to an excellent example of successful indirect State co-ordination of industry in the Government postal service (service not control). Here is no despotic dictatorship—no rules and regulations to control commerce, no interference with individual effort, and yet has there ever been a more potent influence upon the conduct of industry?

If an attempt is made to imagine commerce conducted without the aid of the postal service, the effect such service has had upon all industries will be appreciated immediately.

This is an instance of a Government department conducted on strictly business lines, and yet neither trading nor competing with any industry. It is financially self-supporting, and in fact contributes large sums annually to the revenues of the country, by the levy of an exceedingly small toll for services rendered.

If some system of overseas trade service were inaugurated and run by the State, or by State and private enterprise combined, on the same general lines as the postal service, it should be a great boon to all industries. A service of this nature is by no means so impracticable as may at first sight appear.

It must, however, be essentially a public service and not a trading concern, its first aim being to afford British subjects in all parts of the world facilities for procuring British-made engineering products on satisfactory terms, and its second aim to furnish British producers with the fullest possible information respecting overseas requirements.

The Co-ordinating Influence of Engineering Standards.

Another illustration of sub-conscious co-ordination of industry, which should appeal particularly to engineers, is the invaluable work already achieved and in progress by the British Engineering Standards Committee. By preference—rather than by enforced rules—the many standards formulated by this centralizing organization are increasingly being adopted by the majority of engineering works throughout the country. The reason for their adoption is not far to seek, since it is now generally recognized that standardization is of paramount importance to economic production.

General Conclusions.

Notwithstanding all that has been done in the past to maintain and improve British overseas trade, there is abundant evidence that the results achieved fall very short of possible attainment. For instance, a large amount of machinery and engineering appliances of all descriptions is imported into Canada every year, but it is estimated that less than 5 per cent of these imports are manufactured in the United Kingdom.

The author's opinion is that maximum efficiency will only be attained by grouping the various elements, upon which successful overseas trade is dependent, under three self-contained closely allied and interconnected sections which may be classified respectively as:—

(*a*) Production; (*b*) Co-ordination; (*c*) Distribution; the suggested co-relation and constitution of these respective sections being shown diagrammatically in Fig. 1.

Production.

The sole aim of those responsible for production should be to manufacture appliances to meet the ascertained requirements of overseas markets (f.o.r. their own works) at minimum prices consistent with reasonable manufacturing profits and a liberal scale of wages to employees. In order that producers may be free to concentrate their entire efforts upon improving the efficiency of production, it should not be necessary for them to devote their attentions to the many intricate problems associated with overseas trade. At the same time, they should be entirely untrammelled by any unnecessary restrictions in the management of their respective businesses in which they, and they alone, are experts.

Co-ordination.

Co-ordination may be defined as the most efficient utilization of all existing and potential factors of production and distribution.

There are at the present time so many organizations devoting their attention to the problems of co-ordinating and re-constructing industry—particularly the engineering trades—that it is difficult to follow and keep in touch with the various projects which are being formulated. Of the State and private enterprise undertakings dealing with this matter the following are perhaps the best known:—

The Ministry of Reconstruction.
The Board of Trade, Foreign Office, and Consular Service.
The Chambers of Commerce.
The British Engineering Standards Committee.
The Federation of British Industries, etc.

Whilst these organizations are attacking the problem from different aspects, they are all aiming at a common

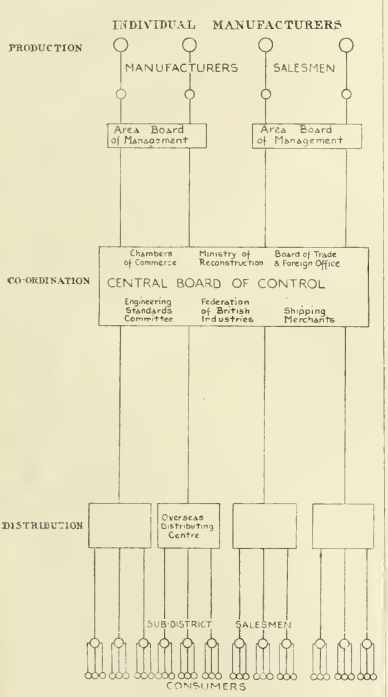


FIG. 1.

objective. It appears to be, therefore a primary necessity that their efforts in this direction should be all co-ordinated under one central control which would be the universally recognized centre for all matters relating to overseas engineering trade. This Central Board might advantageously consist of a representative of each of the individual organizations referred to above, with the addition of a representative of existing shipping merchant interests. The primary object of the board should be to endeavour to maintain a constant balance between the factors of British supply and overseas demand, for which purpose it is necessary that its members should be kept constantly informed as to—

(*a*) What are the predominant existing or potential demands of each of the various overseas markets.
(*b*) What is the nature and extent of the productive capacity of each of the engineering manufacturing units in this country, including all works from the limited number of firms employing tens of thousands of operatives to the many thousands of works employing a comparatively small number of operatives.

Information under catagory (*a*) would be obtainable from the existing records and statistics of the Commercial Intelligence Department of the Board of Trade, which records it is presumed will be supplemented and greatly amplified in future by consular or commercial attaché reports. The more detailed information upon which future trade must principally depend can, however, only be obtained satisfactorily through the medium of organized selling forces actually trading in each of the respective districts from which information is required. Existing organizations, such as the established overseas branches of city shipping merchants, should be used for this purpose, but where this is not possible or in the many overseas territories where city shippers are not represented, distributing centres must be organized to serve the double purpose of keeping the Central Board informed respecting the requirements of each such district and of procuring orders for British-made appliances.

Very complete information respecting the productive capacity of engineering works throughout the country is already in the possession of the several "Munitions Area Boards of Management" created by the Ministry of Munitions for the purpose of procuring the maximum output of war material.

This decentralized system of purchasing engineering products, which has proved to be such a satisfactory method of procuring munitions on an economic basis, should be even more beneficial for the purchase of the large variety of engineering requirements for overseas trade.

Distribution.

To provide for anything approaching efficient distribution of engineering appliances, it is necessary that in every overseas industrial centre a complete distributing organization shall be established, consisting of a business general manager, an engineering staff, a number of sub-district salesmen (preferably local men well-known to every potential buyer in the particular sub-district allotted to them), an accountancy and credit department, adequate clerical assistance, warehouse and showroom or exhibition accommodation, etc.

The managers of the respective distributing centres should be men possessing tact, initiative, judgment,

and resource, as well as a wide field of general knowledge. They must be given absolute authority to enter into and execute all contracts without reference to headquarters, though they should report to the Central Board all transactions completed each week.

The engineering staff should consist of men who have been trained in engineering works in this country and who are consequently familiar with British workshop practice and British standards. They would advise local buyers as to the type of British-made plant best suited to their individual requirements, and would carry out contracts for the erection of complete installations where required to do so.

The sub-district salesmen (or local travellers) would be allotted separate areas to work, of such a size as to enable them to keep in touch with all buyers of engineering appliances in their respective areas. Unlike manufacturers' salesmen, who are rightly expected under all circumstances to push the sale of their own principals' products only, distribution salesmen would be required to report to the local district office all prospects for engineering work of any description. Their sole aim would be to procure the maximum possible turnover in British-made appliances without favouring the products of any individual firm.

A good and trustworthy credit department is an absolutely essential adjunct to every overseas distributing centre. The usual terms of payment in, say, Canada, are 60 days after delivery at purchasers' works, or alternatively, part payment on delivery and the balance in instalments frequently extended over very long periods. The local banks invariably discount purchasers' promissory notes and make collections through their various branches when due. The principal safeguard against bad debts is an efficient credit department. Every wholesale distributor submits all important orders, before executing them, to his credit manager, who either knows or has means of ascertaining what is the financial position of every buyer, or prospective buyer, in the territory.

An important institution in Canada is the Canadian Credit Men's Association, with a membership of considerably over 1,000 representatives of the principal wholesale distributing houses scattered over the entire Dominion. The main object of this organization is to render more stable and secure the wholesale credit trade of the country. During the exceedingly acute period of depression following the bad harvest of 1914 and the simultaneous outbreak of war, the Association considered whether it was desirable greatly to tighten up terms of credit. It was, however, generally agreed that any appreciable departure from previous practice in this respect was both impracticable and undesirable.

The author had the privilege of serving on one of the executive committees of this Association when in Canada, and he was thereby afforded an insight into the exceedingly valuable work this institution is carrying out. He is confident that under the guidance of the Association referred to, and with the help of an efficient credit department at each Canadian distributing centre, the risk of excessive bad debts through trading in engineering appliances is small. Any attempt, however, to give or control credit from this side would be bound to lead to heavy losses on this account, or alternatively to the loss of a large amount of profitable business.

The pricing and estimating department is possibly the most indispensable section of an overseas distributing centre. Numerous inquiries by mail and telephone, all calling for immediate attention, are received daily, and the conditions to be met are so varied that it is seldom an estimate prepared for one scheme can be used without modification for another inquiry. British manufacturers are frequently recommended to price their catalogues in the currency of the country in which they wish to do business. For engineering work this would usually be of very little, if any, value, since the cost of a plant f.o.b. English port is of no interest to the average overseas purchaser, who invariably requires the cost erected on site—say 2,000 miles from the coast and possibly some miles from the nearest railway siding—which cost will amount to from 150 per cent to 300 per cent, or more, of the f.o.b. cost. Moreover, inquiries invariably call for composite tenders covering appliances made by a number of different firms. Thus a quotation for, say, a pump would usually not be considered unless it also included a petrol engine, suction gas plant, electric motor or other means of driving it, with switchgear, sundry pipe work, valves, tanks, etc. Performance specifications and detailed operating costs are also required with each tender. Altogether the organizing of an efficient overseas estimating department with the necessary preliminary collection and recording of manufacturers' f.o.b. costs, shipping weights and dimensions, ocean and inland freight charges (which are constantly changing), customs and insurance charges and complete technical data is a very laborious and costly proceeding.

Extensive warehouse accommodation must be provided at every distributing centre, of sufficient capacity to provide for carrying a large and varied stock of those appliances for which there is a reasonably big demand. Quite apart from the necessity of being in a position to make immediate deliveries from stock, a very considerable saving in freightage charges can be effected by importing goods in car-load (10 tons) lots. For example, the pre-war freight charges on a 60-h.p. horizontal gas engine from London to Calgary amounted to approximately £100, or roughly 60 per cent on the f.o.b. cost of the engine. If two similar engines had been shipped in one consignment the freight charges would have been approximately £60 each, or only 36 per cent on the f.o.b. cost. By taking advantage of these, and other points, the total cost of freight duty and insurance between London and Winnipeg is frequently not greater than between Winnipeg and many manufacturing centres in the United States, since the preferential duty on British-made goods tends to offset the additional freight charges.

Operating Costs of Overseas Distributing Centres.

As very few people in this country appear to have any idea of the cost of running an overseas distributing centre (manufacturers frequently suggest 5 per cent as an adequate selling commission), the particulars of a year's costs, shown in Table 1, actually incurred

in one of the industrial centres of Canada, may be of general interest. Every item of cost was constantly and closely scrutinized and reduced to a minimum consistent with the large area to be covered.

TABLE 1.

	£
Rent, rates, taxes, and insurances	1,205
Salaries, management, engineering, and clerical	2,482
Salaries, salesmen, and travelling expenses	1,793
Packing and delivery charges	764
Office supplies, advertising, legal, and general expenses	572
Bank charges, interest, discount, and exchange	310
Postage, telephone, and telegrams	241
Depreciation and bad debts	396
	£7,763

Total turnover during period covered by above operating costs=£30,013.

Ratio of operating costs to turnover 25·8 per cent.

Gross profit, £7,012=22·4 per cent of turnover.

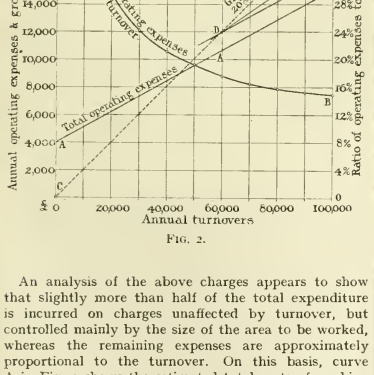


FIG. 2.

An analysis of the above charges appears to show that slightly more than half of the total expenditure is incurred on charges unaffected by turnover, but controlled mainly by the size of the area to be worked, whereas the remaining expenses are approximately proportional to the turnover. On this basis, curve A in Fig. 2 shows the estimated total costs of working a similar area with an annual turnover ranging from zero up to £100,000.

Curve B shows the corresponding ratio of operating costs to turnover. As the average gross profit usually will not exceed 20 per cent, a turnover of approximately £45,000 per annum must be exceeded before any net profit can be shown.

The distributing area in which the results shown in Table 1 were obtained is known as the Middle West or Prairie Provinces of Canada. It is bounded on the East by the Great Lakes and on the West by the Rocky Mountains, the chief centre of distribution being the City of Winnipeg. Some particulars of the developed portion of this area, given in Table 2, will show how impossible it is to work such a district efficiently without incurring heavy operating expenses.

TABLE 2.

Extreme length of district, E. and W.	1,300 miles
Extreme width of district, N. and S.	300 miles
Approximate area	160,000 sq. miles
Approximate total mileage of railways	10,000 miles
Approximate number of towns having a population of over 500	150
Aggregate population of above towns	770,000
Average population per town	5,000
Number of rural post offices in addition to above towns	3,400

The rural post offices are chiefly mail-distributing centres for farmers, who it must be remembered are all potential buyers of engineering appliances, including agricultural machinery, motor-cars, pumping plants, heating and lighting installations, etc.

It is a popular fallacy that the farms in Western Canada are very large and scattered; but cultivated farms of over 1,000 acres—which would not be considered a large farm in England—are quite the exception in Canada. The author found, on making a house-to-house canvas, in a well-settled district about 100 miles north-west of Winnipeg, that a tract of land 18 miles long by 6 miles wide was occupied by no less than 224 farmers—the average size of the holdings in this area being 380 acres per farmer. Of the above, 186 farmers owned the land occupied, and 38 were tenant farmers. This particular district is typical of a large number of other districts aggregating many thousands of square miles similarly occupied.

FINANCE.

In endeavouring to compute what capital or financial backing would be required to carry out the overseas engineering trade service proposed, one encounters the difficulty that the engineering industry covers anything from, say, the supply of the smallest electric motor to the equipment of a bulk-supply power scheme or the building of a railway. Whilst the organization, through its overseas distributing staff, would find many opportunities of rendering valuable assistance in connection with heavy engineering schemes, its principal source of revenue would probably be the profits on trading in general engineering merchandise of a kind that would be handled by shipping merchants.

Reference has been made to the desirability of procuring the collaboration of shipping merchants in all markets where such merchants have established distributing branches. The co-operative purchasing, and other features of the proposed central control scheme,

should greatly increase the previous profits and turnover of these established businesses—on the other hand, their experience, local knowledge and trade connection should be invaluable to the central organization. It is suggested that as an inducement to such firms to merge their businesses in the co-operative scheme (whilst retaining local control), they should be guaranteed an annual net profit equivalent to the average net profit during the three years prior to the war, and that they should retain in addition one-third of the extra profit earned each year as the result of the larger turnover and other benefits accruing from their amalgamation with the central organization. The remaining two-thirds of the excess profits would be applied towards meeting the expenses of the Central Control Board.

As a hypothetical illustration of the application of this principle, let it be assumed that the "operating cost" and "gross profit" relatively to "turnover," of a given overseas distributing centre, are correctly represented by points on curves A and C, Fig. 2, and that the average annual turnover for three years prior to the war had been £60,000, in which case the net profit would be £1,400, represented by the ordinate (D—A). Then (D—A) is the merchant's guaranteed net annual profit for any turnover, and (E—A) is his share of the total profit, whereas (C—E) is the proportion of the profit of this distributing centre payable to the general fund.

Now, if the average turnover of a given distributing centre during the first five years following the amalgamation is £80,000 per annum (the ratio of gross profit to turnover being as shown in Fig. 2), the merchant's share of the profit (E—A) will be £2,000 and the contribution to the general expenses (C—E) will be £1,200.

The local or overseas control of each distributing centre would continue as before the amalgamation, and would not be under the direction or control of the Central Board, except that, should the Board have cause to be dissatisfied with the management or conduct of any of the associated overseas branches, they would have the right to terminate all association with such distributing merchant upon giving reasonable notice to that effect.

Let it now be assumed that the central organization has associated with it 100 distributing centres in various overseas territories, of which number 50 are existing merchants working under the co-operative scheme described, and the remaining 50 are new branches established by, and under the control of the Central Board, the latter branches having been established in territories where there were previously no merchants trading in British engineering appliances, or where existing merchants were unwilling to collaborate with the central organization. Let it also be assumed that the average turnover of the 50 associated merchants' distributing centres during the first five years' working of the new scheme is £80,000 per annum, and that the average turnover of each of the 50 newly established centres is £40,000 per annum (the ratio of gross profit to turnover being in all cases as shown in Fig. 2), then the net result of the first five years' trading, as far as the overseas centres are concerned, would be:—

	£	£
50 centres each contributing (C—E) = £1,200 per annum for five years	= 300,000	
Less loss on 50 new centres (C—A) = (—£400) per annum for five years	= 100,000	
Aggregate net profit of all distributing centres	= 200,000	
Estimated cost of central office expenses—1½% on turnover of £27,500,000		= 412,500
Net loss	= 212,500	
	£412,500	£412,500

Some such result must be expected during the initial or constructive period, but during the second five years it is reasonable to anticipate that the results should be approximately as follows:—

	£
Average turnover of 50 associated merchant distributing centres—£100,000 per annum each for five years	= 25,000,000
Average turnover of 50 directly controlled distributing centres—£60,000 per annum each for five years	= 15,000,000
	£40,000,000

	£	£
Central office operating expenses for five years—1½% on £40,000,000		600,000
Contribution from 50 associated merchant distributing centres (C—E) = £2,400 per annum for five years	= 600,000	
Profits of 50 direct controlled centres (C—A) = £1,400 per annum for five years	= 350,000	
Net profit		350,000
	£950,000	£950,000

Thus by the end of 10 years, the loss of £212,500 during the first five years would have been liquidated and a reserve fund of £137,500 would have been accumulated, which result would doubtless lead the Central Board to amend the charges towards the central office expenses, thereby tending further to increase the annual turnover. By this means, producers, distributing merchants, and consumers would all benefit, and the central organization would have rendered an invaluable service to the community and would not have traded for profit.

It is estimated that the total capital required for trading and working expenses would be approximately one-third of the annual turnover; thus, for the above estimated turnover of £8,000,000 per annum a capital of £2,700,000 would be required. It is suggested that this capital should be raised by public subscription for bonds, the interest and re-payment of which should be guaranteed by the State.

It now remains to consider what would be the procedure if some such general scheme of production,

co-ordination and distribution, as is recommended, was adopted as a means of improving overseas trade.

It is suggested that the Area Boards of Management should at once confer with manufacturers in their respective districts, with a view to ascertaining what standard British-made engineering products would be likely to find the most ready sale in overseas territories. Every manufacturer would naturally advocate the inclusion of his own particular specialities. It is, however, imperative that a start should be made with a very limited assortment of types of products, and that the entire selling force should be concentrated upon testing all the various markets with these first. The Area Boards of Management would therefore be required to exercise great discrimination in making their preliminary choice. The recommendations of the respective Area Boards of Management would be submitted to the Central Board of Control, who would be guided, in making their final selection, partly by the advice of the Board of Trade and shipping merchant representatives on the Central Board, and partly by the preponderance of recommendations received from the Area Boards of Management. When the selection of types of machinery, etc., to be handled in the first instance was definitely decided upon, the Area Boards of Management would be requested to obtain from all manufacturers of the selected appliances complete lists of prices f.o.b. works or English port, shipping weights and dimensions, and technical data. The whole of the information collected would be sent to the Central Board, whose executive officers would dissect it and compile from it comprehensive price lists covering all sizes and types of each appliance. Specifications would be prepared to embrace the designs of the greatest number of firms whose prices were satisfactory and would be embodied in the general price list of, say, electric motors. No makers' names would be referred to in these lists, as the appliances would be marketed as " British Co-operative " products. The f.o.b. English port price would then be embodied in a number of different lists which would also give the delivered prices at all the respective distributing centres throughout the world, the latter lists being compiled exclusively for the use of the officers at the respective distributing centres. The f.o.b. prices, ocean freight, inland freight (car load and less car load), insurance and customs charges, would be all tabulated and shown as separate items to facilite rapid adjustment to correspond to changing freight charges.

Immediately upon the termination of the war, the Central Board would make the necessary arrangements for the establishment of distributing centres in every overseas industrial centre, utilizing existing selling organizations where possible. The price lists already prepared with sufficient technical data would be forwarded to the general manager of each distributing centre, and the respective estimating departments would prepare local price lists in the coinage of the country, embodying any necessary local charges, margins for discounts, etc., respecting which the central executive would have no knowledge. These local price lists would be freely distributed, together with the British Standard Specifications available, amongst all potential buyers, and would provide material to enable distribution salesmen to commence their campaign. This would enable the latter to gauge the demand and to report to their respective local centres what sizes and types of apparatus it would be most profitable to stock at the local warehouse. When the Central Board was in a position to place orders, either for stock or to fill direct orders, they would advise the Area Boards of Management of their requirements and the latter would obtain tenders from all manufacturers in their respective areas. After the orders had been placed, the executive officers of the Area Boards of Management would superintend production and testing, etc., and would take all necessary steps to ensure dispatch according to contract.

In making their investigations respecting the potential demand for the listed appliances, salesmen would receive many inquiries for other appliances, which they would report to their local manager, who would pass on to the Central Board those inquiries which he considered to be genuine prospects of business. In many cases such inquiries would be for plant of a type that is not made at present by British manufacturers. Should a sub-district salesman report such a demand, the local manager would instruct all his salesmen to ascertain and report as to the probability of the requirement becoming sufficiently general to justify its being followed up as a standard speciality. If satisfied on this point, he would immediately arrange for his engineering staff to investigate the matter and prepare a full and lucid specification of the exact technical requirements of the prospect. This specification would be forwarded to the Central Board who, if they thought fit, would send copies of it to every other distributing centre for criticism by the respective engineering staffs, with a view to ascertaining whether the technical requirements were the same in their districts. Should the replies from the majority of distributing areas be such as to satisfy the Central Board that the world demand was likely to be large, the Board would then submit the specification of requirements to one or more consulting engineers recognized as the leading experts in the particular matter referred to, who would prepare designs and specifications of a plant to meet the requirements. Such specification would then be distributed to all suitable manufacturers through the Area Boards of Management.

Conclusion.

In the foregoing notes the author has referred to various points based on personal observations made during the past 15 years, a considerable portion of which time has been spent in overseas territories. The points he particularly wishes to emphasize are the following :—

The national welfare of the British Empire is so dependent upon the engineering industries, that the use of State credit for the purpose of improving the overseas distribution of engineering appliances appears to be justifiable.

" State control " of industry upon German lines would tend to stultify " individual enterprise," which is the foundation of British supremacy.

" State service " analogous to the Government postal service, having for its object the extension of the

benefits of modern civilization to British subjects in all overseas territories, without necessarily aiming at making immediate profits, would greatly strengthen the bonds of Empire and would ultimately create an enormous demand for British products.

Overseas trade in engineering appliances should be conducted on the lines of bulk electricity supply, especially in regard to the treatment of production and distribution as distinct but allied branches of the industry.

The management of engineering overseas trade might advantageously be co-ordinated under a Central Board of Control composed of representatives of each of the several organizations (State and private enterprise) at present devoting attention to this purpose. Such Board of Control should aim at establishing distributing centres in every overseas market to serve as connecting links with consumers and might employ a decentralized purchasing agency, consisting of Area Boards of Management, to serve as a connecting link with manufacturers.

The *New York Times*, 29th December, 1916, says:—

"The nation that will really win the war will be the one that can the most quickly recover from its effect, and the most quickly resume its place in the race of industrial competition."

It might be added that the place so occupied by each nation will depend chiefly upon its powers of "dovetailing the individual-self into the community-self." This Germany claims to be "pre-eminently able to achieve," which claim, it mst be admitted, is no idle boast. "Organization, combination, and State collectivism are the distinguishing marks of German economic life," * though whether these characteristics tend to produce a desirable citizen is questionable.

The American Declaration of Independence says:—"Man is endowed by his Maker with certain inalienable rights amongst which are life, liberty and the pursuit of happiness." If British industrial life were based on these principles, the welfare of the community as a whole, as well as the freedom of the individual, would be safeguarded.

APPENDIX I.

Exhibitions as a Means of Promoting Overseas Trade.

Permanent exhibitions of British-made machinery in some of the principal overseas cities have been proposed as a means of affording overseas buyers an opportunity of acquiring information respecting such appliances.

Some four years ago the author tried the experiment of exhibiting a variety of British machinery in a large showroom having a good show-window facing one of the most frequented streets in the centre of the city of Winnipeg. The experiment was not a success, as the mere exhibition of standing machinery still failed to afford prospective buyers an opportunity of forming an opinion as to what the performance of such machines would be under running conditions. Arrangements were made consequently to remove the machines to another building less central, but with facilities for showing all the machinery in motion. Some 30 different exhibits consisting of centrifugal pumps, air compressors, country-house electric lighting plants, etc., were all connected up and shown in operation to indicate the special features of each appliance. One of the centrifugal pumps was connected to a variable-speed motor, and experiments were shown to demonstrate the effect of speed and head upon the volume of water lifted. An air compressor was connected to an air-lift water installation and the effect of varying the percentage of submersion of the air pipe was demonstrated. A combined petrol engine and electric generator plant was connected to a bank of incandescent lamps and the perfect governing of the engine from no load to full load was shown by switching the entire load, or sections of the load, on and off. Demonstrations lasting about two hours were given twice daily with a short lecture on each exhibit.

The demonstrations were attended by a large number of engineers, architects, city and Government officials, and others interested in engineering work, nearly all visitors remarking that it was the first opportunity they had been given of appreciating the admitted superiority of British workmanship and design in the various appliances exhibited.

* *Quarterly Review*, October, 1917, p. 421.

APPENDIX II.

Pre-War Channels of British Overseas Trade.

In 1910–1911 the author visited many of the principal cities in Canada, Australia, New Zealand, and India, for the purpose of investigating prospects for British engineering trade in these countries. He was thus afforded opportunities of forming an opinion as to the advantages and disadvantages of the methods adopted by British firms catering for these markets.

The most efficient example of co-operation between producer and distributor met with was that of a firm of Anglo-Indian merchants having distributing centres in Calcutta and Bombay with a buying office in London, and representing as sole agents for India a limited number of well-known British engineering manufacturers. The principals explained that they made it a rule to refuse any agency offered them unless the manufacturers concerned were prepared to send out, at their own cost, a fully qualified technical expert to work permanently in their Indian offices, and to push the sale of and deal with all technical points arising in connection with the manufacturer's own appliances.

The merchants provided what the manufacturer's representative could have acquired only after several years' residence in the country, namely, an excellent connection with all local buyers, a thorough knowledge of the trading conditions of the country, a knowledge of the financial stability of all buyers, local warehouse, showroom, and office accommodation with all clerical assistance, and finally full knowledge of economic shipping facilities and requirements, respecting which many British manufacturers are entirely ignorant.

The respective manufacturers' representatives furnished the specialist's selling experience required, based on a thorough training in the firms' own works, such as no foreign agent could possibly obtain respecting even one manufacturer's products and obviously much less so respecting a number of different makers' appliances.

The producers invoiced to the merchants the goods supplied at bare manufacturing cost, and received payment against shipping documents. The difference between such manufacturing cost plus shipping charges, etc., and the ultimate net selling price was eventually divided between the manufacturer and the merchant.

Discussion.

Mr. P. Griffith: It is very desirable that in matters of this kind the initiative should emanate from the trade itself rather than from the Government, because, in this country, progress s only possible while free play is allowed for the element of private initiative, the alternative (so strongly displayed in Germany) being utterly foreign to our nature. With this thought in mind I desire to protest against the constant use by the author of the word "control." No doubt he had not intended to represent quite what this word implies; but if this were so, as was indeed proved by his omission of the word in reading the paper, it would be desirable for him to substitute some other title for the Central Board representing the element of co-ordination in the diagram on page 371. The manufacturers at any rate would never consent to be controlled by any quasi-governmental department of the kind suggested, and if they did, our commercial supremacy would, I am afraid, soon disappear. The dominant idea which appears to prevail in the author's mind would be better expressed by the word "federation" than by the term "Board of Control," and if he would admit this, his suggestions would probably receive far greater sympathy than they would do otherwise. Before dealing with the author's scheme as a whole, I wish to criticize his statement that, at the present time, "the absence of competition between engineering manufacturers has not tended to increase the cost of production," and again the statement that "the decentralized system of purchasing engineering products . . . has proved . . . a satisfactory method of procuring munitions on an economic basis." Both these statements are contrary to the facts. Munitions have certainly been provided under circumstances of extreme urgency; but when the details of cost are fully revealed it will be seen that the system has proved the reverse of satisfactory from the economic point of view; for, on the one hand, the nation's money has been squandered with reckless prodigality, and, on the other hand, many small engineering firms have lost large sums of money in undertaking work entirely outside their province. The procedure adopted to meet this emergency is certainly not one to be adopted in peace time. In regard to the financial aspects of the author's scheme, it is of course obvious that any elaboration of administration must involve extra outlay, and it is equally obvious that this extra cost (which, by the way, will include extra capital as well as maintenance charges) must be provided by the trade. This, however, would not apply if any part of the system were controlled by Government departments, for the two factors—finance and control—are mutually interdependent; in other words, to secure independence as regards control the trade must maintain its independence as regards finance. Thus one may ask the author why, in providing for a certain amount of Government control, he has not provided for any financial assistance from the same source. The scheme appears to me to be complex and unwieldy, more particularly in placing such a wide gulf between the manufacturer and the user of engineering appliances. In new countries, such as those to which the scheme would for the most part apply, it seems essential that direct communication between user and manufacturer should be constantly maintained. The principal defect of our old-time method of trading has been our reluctance to modify our designs to suit local conditions, standardization under such conditions being a disadvantage rather than the reverse. The process by which local demands are to be ascertained, reported to the manufacturers, and met, is so cumbersome that by the time any special or unusual demand could be met the goods would have been supplied from America or even from Germany. The factor which seems to have been overlooked by the author is the personal factor, and I consider this to be the most important of all in the engineering industry. Speaking very broadly, my idea is that the case could be met by a development of the functions usually assumed by the consulting engineer. The author has gone a long way towards the end in view by suggesting that local representatives should not act as commercial travellers working in the interests of individual firms, but should represent British manufacturers as a whole. This, however, does not allow for the fact that no one man can, in these days of rapid progress, be familiar with more than one branch of engineering. To meet this difficulty the engineering industry must be subdivided into sections, each of which will be within the grasp of one man, or groups of men distributed over given areas of distribution. The local agents of each section will have to be experts capable of giving reliable and independent advice on all questions of design. Thus the word "salesmen" employed by the author would be inappropriate as applied to expert engineers with technical as well as commercial training and experience. It may be suggested that a sufficient supply of such men could be found among the ranks of the consulting engineers who are more and more being displaced by the manufacturer's agent. Research or experiment with novel methods of manufacture cannot be carried out or encouraged by manufacturers of competing goods, and the results quoted and advertised by interested parties are bound to be unreliable; hence an important function devolves upon the independent local agent, namely the valuation of the rival claims of competing goods,

and this would undoubtedly prove a great advantage to our national industry and would probably secure larger orders for each branch of engineering than are obtained by the present system of unrestricted competition.

Mr. W. L. Madgen: The last speaker has expressed many of my views upon this matter, but I should like to qualify them in some measure. He has referred to the unwillingness of the British manufacturers to vary from standards for the purpose of satisfying some particular consumer. That is an argument which was a very favourite one with the halfpenny papers some years ago in their diatribes regarding the English manufacturers, but I should like to point out that these islands have only a population of about 45 millions as compared with 70 millions in Germany and 100 millions in America, and we must surely make some selection in regard to our manufactures. We cannot possibly manufacture every kind of everything, so that I think the utmost efficiency is to be achieved in large measure by carefully selecting our manufactures and our standards and by pushing them for all they are worth. I have been occupied this week in testifying before a Parliamentary Committee as to the benefits of the production of electrical energy on a large scale against intense opposition, so that I can well appreciate the broad principles of the paper. I have been very much interested in the table on page 371. The broad space entitled "Co-ordination" is occupied by Chambers of Commerce, the Ministry of Reconstruction, the Board of Trade and Foreign Office, the Engineering Standards Committee, the Federation of British Industries, and Shipping Merchants. I doubt very much the efficiency of such a body. It would be very apt to degenerate into a wholesale distributor of admonitory literature and *questionnaires* substituting, as some one has expressed it, extensive circularizing for intensive thinking. I should like to endorse, as a considerable buyer of machinery of various kinds the remark made by Mr. Griffith. If we want to buy turbines we want the man who comes to see us to be competent in what we want. I daresay we ought to know, but we do not know as well as he does the changes in practice owing to troubles that the manufacturers have experienced, and we want him to help us. It is the same with switchgear. If we want to buy switchgear we send to the manufacturer of switchgear, who comes to see us. He is able to sketch out and discuss the particular thing that he thinks we want, and to show us where we may be wrong. If we attempt to form a body which sells a very large variety of material in Canada, or Australia, or South America, I have not yet seen how we can combine with it that special intimate knowledge of each subject which the buyer requires should be at his service in making his selections.

Mr. L. B. Atkinson: The author has laid particular stress on the necessity of abandoning the old methods of single-handed selling of goods in overseas trades, and that is the point on which I feel very strongly. We are up against a more or less impossible proposition if we are going to try to push British trade overseas in the future on the methods which we have tried in the past. For the purpose of reinforcing my remarks I have two slides which I will put upon the screen. The first is from the Report on Co-operation in American Export Trade recently published by the American Government, and shows the Allgemeine Elektristäts Gesellschaft in the centre, and round it the various companies which are distributed all over the world, the A.E.G. being directly represented on them by its own directors or engineers. Those embody supply companies, trading companies, banking companies, and merchant companies. That is the organization which that big German concern has set up in the past, and with which it has operated in the past, and with which our traders have endeavoured single-handed to cope in dealing with their businesses. Many of our largest manufacturers are not the size of a single one of those companies; and one of them, the Deutsche Bank, is in itself practically a representative of the German Government. The next slide is one that I extracted from the celebrated Report of the Pujo Committee on the Concentration of Money Control in America (1913). In the centre is a circle showing the three principal money concerns which at that time controlled the American business—J. P. Morgan & Co., the National City Bank, the First National Bank, and one other concern; all the big circles on the lower left are railroad concerns. In the top left-hand corner are the manufacturing and trading concerns, and amongst them the General Electric Company and the Westinghouse Company. In the right-hand bottom corner are all kinds of finance and trust concerns. In the upper right-hand corner are public utilities. All those concerns are interlaced by direct representation on their Boards, radiating from that one centre, and we can make up our mind that when people are connected to one centre like that they are not doing it without using the whole of the influences they represent to push their trade. So far the Americans have not pushed their trade to any great extent by any such organization abroad, but they are making up their minds to do it now. The extent to which they intend to go is well shown by the Government's action, which, although it to a large extent dissociated many of those controls in the home market, has given permission for their combination for the purpose of outside and overseas trade. That is the sort of combination we are going to be up against from the Americans; and I have just shown the sort of combination we have been and shall be up against from Germany. We are wasting our time and efforts unless we do something to co-ordinate our efforts and cease the old-fashioned method of individual trading abroad. Whether the proposal made by the author is the best is a question we could debate for days, but I think probably all of us are agreed that the extent of Government control he has mentioned would make it almost impossible among the engineering world to-day to get any consensus of opinion even to try to discuss such a scheme. On the other hand, there is among the British people and engineering people an immense difficulty in getting them to sink their individuality, their old brands and trade-marks, and present business activities, in favour of any kind of co-operative action, because they fear they will not

maintain the same amount of business they individually did before. What we have really to do, by papers like this and other means, is to convince British engineering manufacturers that they will increase their business beyond anything they have ever imagined if only they will combine to do this foreign business ; and the same holds true to a less extent of home business. The solution which I propose is the joint action of individual concerns through the Association covering their own trade, and in certain cases joint action of several Associations covering allied trades. Thus each trade is working with and through an organization it trusts and which understands its needs, and I am convinced this is a more practicable basis than action through new bodies to deal with trades they do not understand. If Government support is necessary it will, in the present Government policy, be afforded to Associations representing industries, and I think the ground is ready and the time ripe for a movement by the electrical industry on these lines.

Mr. A. Newlands : The author has incidentally referred to a subject in which I am much interested, namely, Boards of Management. Members of the Institution are probably more or less conversant with the necessity which caused the formation of such Boards. Early in the war it was found that the maximum output of shells from the armament group was hopelessly inadequate to meet our requirements even after they had enlisted practically all engineering firms whom they considered able to be of assistance. Sir James (then Mr. James) Stevenson brought forward a scheme of co-ordinating the less important firms throughout the country. For this purpose he caused to be formed a series of Boards of Management. He divided the United Kingdom into 40 areas and procured the assistance of groups of the keenest and best business men, who gave their services as members of the Boards gratuitously. The work thus started proved a great success, and these Boards have been the means of production of a very considerable share of the shells and munitions manufactured in the country. This is due to the harnessing up of the smaller firms—a form of co-ordination of production. Had the co-ordination of this country's industry been complete and included all firms, doubtless the results, remarkable though they have proved, would have been still greater. We have however, a very good example of what co-ordination will do so far as production is concerned. Why should not the same success follow co-ordination in search of markets ? The success of the one has been undoubted, and it lies with the trades concerned so to co-ordinate their efforts as to yield successful results.

Mr. P. Rosling : I am afraid I must take a rather different view of the question from that which the author takes, because I do not agree with the diagnosis or the proposed remedy. My experience abroad is that if we compare like with like, that is to say, the British methods of distribution of large houses with the Continental or American large houses, we shall find that the British organization and salesmanship have not much to learn from competitors ; but if we compare the trade done by a number of small individualistic manufacturers of Great Britain with the sales effected by the large houses of the Continent, then we are in a very bad position. The only thing is for the small individualistic manufacturers to get together in combination up to a certain size, not too large, as red tape tends to grow as the square of the size, and appoint their own representatives abroad, exactly in the same way as the large houses in Great Britain have done. In the much praised selling organization of the Germans what do we find ? The Allgemeine had British salesmen in Australia, and their branch there was run by an Australian staff. The General Electric Company of America have an Australian-born staff doing their work. Four or five smaller German firms combined together and formed the Union Electric Company, and they were staffed by Britishers. If British merchants or agents or engineers in the future will remember this war and not help the Germans to sell their goods, I think German products will have no sale in our Colonies at any rate. When it comes to foreign countries, such as China or South America, there the Germans have almost entirely held their place by cheapness. That may not be only a question of quality but of cheaper production owing to greater output. I think that the whole secret of holding the world's market is to hold our own first. Give us our own market, and we can take what we want of the whole world. The British workman is the best workman in the world, and the British engineer and organizer can beat any others in the world. The Americans may come near us ; they have beaten us in Canada, but there they have an advantage in their proximity and in speaking the same language, with the same pronunciation ; they are inter-allied in finance and can visit one another quickly. The bulk of the business done in Canada by the Americans has the advantage of time, which every one in the engineering world knows is a vital advantage in most cases. The author says : "It is an axiom of political economy that no one nation can attain a supremacy over other nations in all industries." It is not an axiom at all, but a postulate, and a postulate of the "Little Englander" politicians who were responsible for the half-penny Press political economy before November 1914. With regard to the analogies given, I think if a power station such as suggested did run successfully when everything was quiet and the load steady, it would go all to pieces when the load varied, as it does in business. The analogy of the Post Office I do not think is good. The distribution and sale of goods requires brains, skill, and initiative, from the management right down to the salesman ; whereas in the Post Office brains and skill are only required in the management, the rest being routine work, which only requires obedience to rules.

Mr. S. Grant : In these proposals there are two analogies, one an electricity-supply undertaking and the other the Ministry of Munitions. The latter may not be a popular one at the present moment. In the organization of the Ministry of Munitions the Area Boards of Management are a very important element. Mr. Newlands has explained how these Boards came into being ; they were created at a time of feverish expansion, when it was absolutely necessary to find new sources of manufacture, and in that respect their work was enormously successful and could not have

been accomplished by any other means. For a long time their scope was confined to a certain class of manufacture and they proved their capabilities in that direction. Now that the Ministry's activities have broadened out very considerably, certain difficulties are introducing themselves into that form of organization, and these were referred to by Mr. Griffith. The root difficulty in organizing by areas is in not being able to distribute expert knowledge to each of the centres. If that expert knowledge is not available in each centre the manufacturer is at a loss, because the information that he requires has to be obtained through a chain which may be fairly long, and in the meantime he does not know how to proceed. The number of links introduced between producer and purchaser is to my mind one of the great disadvantages of such a cumbrous organization as the Ministry of Munitions. I hope that someone may be able to suggest a way in which such a national organization, whether it take the form of State control or State service, can be utilized so as to secure the necessary influence and financial credit to develop our overseas industries, without at the same time failing to meet the problem of such very indirect connection between the producer and the purchaser, and the problem of providing expert knowledge of a sufficiently wide character in each of the centres of organization.

Mr. J. E. Kingsbury: I note in the plan which the author has propounded he has in his ideal system between the producer and the consumer the three stages of the producer, the middleman, and the distributor. It is open to question whether the electrical engineering industry has not suffered from the commercial pre-eminence of Great Britain. It sounds something like a paradox, but we must remember that the export trade of Great Britain has been largely conducted through the medium of British merchants; that has been the system which has been evolved in connection with staple articles and has been productive of great good. In the case of engineering production, where the British merchant could not be expected to have the necessary technical knowledge, the line of development has been rather by direct representation. It might be of interest to inquire to what extent direct representation was introduced by our international competitors because they had not the other methods of communication, or whether it was a distinct recognition of the importance of direct representation in such a subject as engineering. The three stages—producer, middleman, and distributor—would each form ground for much discussion, for which time is not available, but on distribution I might remind members that the author has had a very considerable experience in distribution overseas. It seems to me that if the problem be tackled with a view to correcting or altering some of the features, it may produce good results. The point that wants the greatest amount of attention is the middleman. If the author were to divide the functions of the Board of Control into two bodies, one of which gathered information and the other did the work, it might be productive of some benefit; but as a means of distributing manufactures between the man who makes and the user, I feel it would in its present suggested form be altogether too cumbersome. That may arise to some extent from the analogies which the author has taken in commending his method—the Ministry of Munitions and the Post Office. It must be remembered that the Ministry of Munitions is a despotic power; it was formed for a particular purpose—to produce articles bought by one customer. The Post Office, the author says, is not a despotic power, but I think it is. It is a monopoly and has to maintain its monopoly by the exercise of despotic power. The Post Office is a monopoly, and the Ministry of Munitions is a monopoly, and the overseas trade of the future is not going to be a monopoly. This Board of Control might manage a monopoly very well, but I fear it cannot manage that independent trade in which we are up against competition and in which we have to be free to act promptly and tackle business problems with alertness, initiative, and readiness to take responsibility and some risk. That we cannot expect to be undertaken by a body under Government control.

Mr. F. Broadbent: I do not find any reference to shipping or railway companies on the proposed Board of Control. Assuming the scheme to be ideal, unless we get the co-operation of shipping and railway interests the whole thing is bound to fail. In Germany special rates for export are obtainable on the railways. If machinery is marked "for export" it goes at practically half the rates charged for internal traffic. On canals the rates are considerably lower than those of railways. In our own country the canals have been so neglected that now we can hardly use them and the cost of transport is in some cases higher than by rail. Between 1885 and 1905 the traffic on the canals of Great Britain increased by about 8 per cent, while in Germany in the same time it increased by over 270 per cent. The only cases in England where we get special export rates on the railways are where the railways are in competition with sea-borne traffic, and even then the preference is very small. From Glasgow to Liverpool the pre-war machinery rate was 24s. 3d., but to the Liverpool docks it was 20s. 10d., the reduced rate being to cut out the sea-borne traffic. Although there were price arrangements between the German and the British shipping lines under which the rates were not to be cut below a certain level, we always found that a German exporter could quote cheaper rates from the interior of Germany to any of our Colonies than we could ourselves. Very often British manufacturers could, by shipping to Antwerp or Hamburg, and thence to the Colonies, have saved hundreds of pounds on individual contracts, but were prevented doing so by the rebate system in vogue in this country. Preference given to foreigners by our shipping companies actually cut out the preferential import duties given by our Colonies to British manufacturers. Before the war the Germans could send dynamos or motors from Antwerp, Rotterdam, or Hamburg through the Port of London in British ships, thence to New Zealand, at 40s. per ton, whilst British exporters were charged 62s. 6d. a ton direct from London. The German shipping records would probably show that the proper rate was paid for ocean transport; it was

simply because the German Government gave through rates including railways and shipping combined that the Germans could beat us every time. I have discussed these questions with shipping directors, and their view is that it is their business to uphold British shipping and it is up to manufacturers to hold their own end up. By means of this policy such a big trade between Germany and New Zealand was built up that just before the war the North German Lloyds had started a direct line of ships, some of which were on the way when war broke out. It is obvious, therefore, that the policy has not had the effect, as claimed, of freezing out German shipping. Goods could also be sent from New York to Liverpool, and thence to Sydney, for 5s. a ton less than we could send them to Sydney direct, viz. 40s. against 45s. a ton. From New York to London and thence to India the rate was 2s. 6d. less than from London to India direct, viz. 22s. 6d. against 20s.

Mr. E. T. Williams: Nine years ago, when travelling round a considerable part of the world, I had the opportunity of discussing this problem with various business men and was so convinced that we must tackle it very comprehensively that a series of articles on "The Expansion of British Engineering Abroad" appeared from me in the technical Press. The gist of the articles was that we must take united action. The first thing is to realize how absolutely necessary it is for this country to expand its foreign trade after the war to an extent that is not generally conceived at the moment. If we are going to avoid troubles of all kinds we must have a tremendous outlet for the maximum possible production of the country. I have found that there is a general lack of appreciation in England of the possibilities abroad. Those who have lived in foreign countries and studied the subject are astounded that we at home have not realized how great the expansion can be. Once when I was discussing the problem with a Consul in China he said the home people were always blaming the Consular Service for not doing more, but he really thought the manufacturers were very largely to blame themselves, and he gave me some illustrations. One was that he had a batch of engineering literature sent to him from a home firm with a request that it should be distributed. It was printed in English with English prices and no remittance was sent to cover the labour of distributing, or postage, and it was simply waste paper. The Consuls are not agents. If, after the war, we are going to talk about "Business as usual," as we did when the war started, we shall go down. We have to build up our export trade by organization on rational lines, and, I submit, the keynote of that organization should be collective action. One speaker to-night put the whole thing most admirably when he said that we had to find a method of affording the trader expert assistance without interfering with his freedom of action. There must be freedom for private enterprise. I am in full sympathy with the author in what he is aiming at, although I am sorry to say I cannot agree with the way he proposes to do it. He shows us how to take some profit from shippers; but why should shippers give that profit up? He takes liberty of action almost entirely out of the hands of firms at home for dealing abroad. Then I do not consider his scheme is comprehensive enough, and that any scheme which is going to be a success on big lines must include all branches of commerce. Now is the time to get something really adequate done.

Mr. E. W. Cowan: On the question of principle, I feel, speaking from a manufacturer's point of view, that I do not like the idea of separation of production and enterprise, or, as the author calls it, distribution. Both should be part of a single machine under the control of one mind. The author tells the producer that the right place for him is within the walls of his factory, with his books, his drawings, and his tools. My experience shows me that adaptation on the part of the manufacturer to the requirements of the consumer, and adaptation of the demands of the customer to the producing capacities of the manufacturer, cannot be efficiently realized along the paths of the genealogical type of diagram such as that shown in the paper. I have been engaged for some years in business overseas with a new part of the Empire, and it seems to me to be obvious that this system would not apply in the case of such business. It is my business to maintain active connection between the needs of the consumer and the development of the productions of the manufacturer. I send descriptive bulletins round to plantations in the colony whenever anything new turns up, and also questions as to the working of machinery, and when replies are received I pass them on to the manufacturer, who also sends me copies of letters he receives from other plantations that I do not work for. For that particular kind of trade I cannot conceive of any better system. The author is, I realize, dealing with larger business, but I do not feel convinced that his plan of isolating the manufacturer from those who use his apparatus can wisely be applied to engineering trade upon any scale. It may be effective enough in the case of standard commodities, but it is the process of development of standard apparatus that I fear would suffer by being forced to follow such a circuitous channel as that suggested in the paper.

Mr. A. H. Foyster: I have been privileged to talk to a good many purchasers from overseas and they have given me their opinions very freely on what the author calls our distribution system, and have told me why they have been so often driven into buying American and German goods when they would very willingly have purchased British instead. It is often a long story, but it all boils down to this, that while there are many channels through which our goods, and the knowledge of our goods, go out to them, there is no co-ordination, and while there is overlapping in certain directions, others, which should be available, are missing. To take one example, the ordinary shipping merchant orders goods exactly as the indent states, so if a purchaser overseas happens to describe some machine which is out of date and superseded by a better model, he will not get his order placed. The ordinary shipping merchant does not have, and will not have, on his staff an engineer who could use his discretion in such matters and would frequently be able to give valuable advice to the purchaser. To depart from the

exact wording of the indent would involve the shipper in some responsibility, which the amount of his commission does not cover. His business is to buy exactly what he is told to buy, and by combining several consignments to the same port to reduce the freight charges. Therefore purchasers abroad must know very exactly what can be obtained before indenting, and to do this they have to pay frequent visits to this country to keep in touch with the latest improvements in the machinery of the many manufacturers who are not represented in that part of the world. Even then their knowledge soon becomes out of date, so constantly are machines being improved. Orders sent direct to manufacturers are not considered satisfactory, unless the purchaser is constantly dealing with one firm. The manufacturer is generally paid for the goods long before the purchaser sees them, and when the goods are examined it may be found that some small essential part is missing or broken and there is a delay till a fresh part can be sent out, and sometimes there is a considerable correspondence regarding the responsibility. The author's scheme would do away with many similar disadvantages and I feel sure that it will be welcomed by purchasers overseas, who contend that the American and German distribution systems have up till now been so much more efficient than our own.

Captain R. B. Slacke: To anyone who has been abroad in new countries I think there can be no question that some organization is wanted to meet the needs of these countries, because in many of them they depend perhaps on harvests, and the harvest is very uncertain even in climates not so uncertain as this. The farmer may go three years and live on credit practically the whole time and somebody has to supply him with his agricultural machinery, or else there will be no farming. When he gets a good harvest he can pay off all his debts and have something to go on with. No manufacturer or small group of manufacturers can afford to finance these men, and probably a lot of our ill-success against German and American competitors is due to lack of ability to finance orders, which would be a mere bagatelle to those huge organizations explained by the diagrams that Mr. Atkinson showed. I do not think it is of any use discussing the details of the author's scheme, because we should never come to any result. It seems to me we want to get something done. I saw in to-day's *Times* that a Committee of eminent financiers and others has been appointed to consult with the Commercial Intelligence Branch of the Board of Trade and advise them. Could not the Council of this Institution, combined with the Institutions of Civil Engineers and Mechanical Engineers, put in a word of advice in time and help to build up an organization? It is no use our discussing whether the author's system or somebody else's system is the best, because nothing happens; but if the Councils of these three Institutions could at this stage co-ordinate with that Committee, which I think is the same Committee that had so much to do with the formation of the Trade Bank Corporation, we might get a nucleus of some scheme which would be of advantage. The particular system of the author's may suit one part of the world and may not suit another, and probably local knowledge is wanted of different parts. It is essential, however, that we should first get into touch with the Government departments who are now dealing with these matters.

Mr. H. Allcock: To a very large extent my ideas on the subject have already been voiced by previous speakers, more especially Mr. Atkinson, and I should like to endorse his remarks. How have we hitherto sought to expand our overseas trade? There have been two or three general methods. In some cases the British manufacturing engineer has sent out his own direct representative to the overseas market he wished to exploit. That was necessarily costly and frequently inefficient, because such representatives usually spent most of their effort in competing with other representatives similarly appointed by British competitors. A second method was for the British manufacturer to appoint some local firm of merchants as his agent with or without the assistance of a works-trained engineer. Without such assistance the merchant is relatively helpless in selling engineering products, and with such assistance, if the combination of expert technical ability and local knowledge proves successful, the merchant builds up his business and goodwill at the expense of the home manufacturer, who obtains very little return or security for his enterprise and outlay. A third method is one which, on the face of it, looks rather attractive. This has consisted in the creation of groups of non-competing but allied manufacturers—for instance, an engine maker, a dynamo maker, a cable maker and so forth—who have jointly shared the expense of exploiting the overseas market. Unfortunately a short experience usually ends in these groups breaking down as the result of internal stresses, some of the members complaining that the others reap all the benefit. However fair the proposal may appear at the start, it transpires that the group manager can sell one line of goods while another languishes, so this method also has failed to give universal satisfaction. The solution which appears to me to have the best prospects is for each separate trade within the engineering industry to form a central sales association which, in turn, would send out experts in that trade to each of the overseas markets. These expert technical salesmen would not offer to sell the goods of any one manufacturer but would submit British goods in competition with the German or American or Japanese goods, etc., offered in those markets. The orders so obtained would be transmitted to the central sales bureau of the Association—say in London—where they would be distributed to the members of the Association according to some mutually agreed basis which would be worked out beforehand. I do not think such an arrangement is as far-fetched as it may sound, and I sincerely hope some such attempts will be tried. Before leaving this reference to the Association movement I should like to refer to Naumann's boast quoted by the author, that "This dovetailing of the individual self into the community self is what we (Germans) are pre-eminently able to achieve. . . ." Is the British manufacturer thus prepared to surrender his cherished individualism, even though it be demonstrated to his own satisfaction that such a surrender would be

to his own benefit? I ask the question and leave it at that. I emphatically disagree with the author's suggestion that the State should participate in the control of our overseas trade. I do not thereby consider that the State is a negligible factor, for the State can do many things to encourage our manufacturers to develop their overseas trade. For instance, it may secure and cheapen direct lines of communication between the United Kingdom and the principal markets, establish and protect "key" industries at home, support British enterprise abroad, adopt decimal coinage and the metric system, etc. As the author quotes the Government postal service as his ideal of a State-controlled commercial undertaking, I may remark that for the past 50 years all overseas mail matter has been weighed and paid for by metric weight, including the service between two non-metric countries such as England and America. This recognition by the Post Office of the metric system as the universal language of quantity has yet to be endorsed by the nation as a whole. The recently issued Report of the Committee on Commercial and Industrial Policy after the War [Cd. 9035] states—"The continuance of manufacture on the existing system while the sale of the product had to be made on the metric system would be confusing and inconvenient," so we must regard the retention of our obsolete weights and measures as a hampering influence.

Mr. H. Bosworth: I will confine myself to two points dealt with in the paper. First of all, dealing with the question of State control, the author appears to consider that one of the objections to private enterprise is that it is compelled to make a profit. I should like to see that sentence re-written to say that the fatal objection to Government control is that it is not compelled to make a profit. As soon as we remove that best incentive to efficiency we at once find inefficiency resulting. Business men agree that in many instances this is one of the chief reasons of the inefficient operation of many Government departments. If the suggested Government control comes in I see endless forms, offices, and officials, and all the paraphernalia with which every Government transaction has to be camouflaged, and I do not see the slightest possiblity of such an organization meeting with success. Secondly the author suggests that his overseas distributing centres should obtain the orders, which should then go back to England, and quotations should be then invited from manufacturers and the order be placed on competitive lines. That would suit neither the purchaser nor the manufacturer. The purchaser would certainly be unwilling to buy nameless goods, and experienced engineers abroad, of whom there are many, would not for a moment consider dealing through a third party; they would prefer to go to the manufacturer direct when dealing with any important engineering matter. It would not satisfy the manufacturer, as he would not be willing that his catalogues, his reputation, and his name should be used to obtain orders if those orders, when they came back, had to be tendered for again in England. If such a scheme were carried out the enterprising manufacturer would be compelled to send out his representative to induce the consumer to specify his material, or to short-circuit all this organization and come to him direct. It is all too easy to criticize somebody's proposals, and perhaps it would be more useful to offer a word or two of suggestion. It may not be realized by many people that at the present time there are in England about 45 manufacturers making 5-h.p. electric motors, and not less that 25 firms making generating plant up to 100-kw. capacity. If there were not more than five or six firms making any one size or type of machine, and each of those firms were manufacturing it in large quantities on standard lines, we should find that the cost of the finished article would be reduced in such a way that the whole engineering community would be amazed at the result. Firms making a small range of goods could group themselves together so that they covered a complete range of their products, and five or six firms so combined would have sufficient organization, capital, and foreign representatives, to be able easily to handle their overseas trade. The organization of the means of distribution could be well left to such groups of allied manufacturers, who would be able to give expert information to the consumers. With the industry so organized we should have in each branch of manufacture, cables, motors, switchgear, etc., a series of groups of manufacturing concerns, and it would be an easy matter for each group to co-operate abroad with other groups. For instance, a group of electric motor and dynamo manufacturers could co-operate with a group of oil-engine or steam-turbine or machine-tool makers. There has already been some development along these lines, and if any further Committees or Boards are to be formed it would be well to consider carefully the merits of such schemes as are being developed by the manufacturers themselves, in preference to the very elaborate semi-state organization suggested in the paper.

Mr. R. J. Kaula: I agree with many of the various speakers who have expressed their dislike of the author's Board of Control. If I read the paper correctly, the author wishes to avoid Government control. Yet his proposed organization seems to me to differ very little in character from a Ministry of Exports. Cannot individual producers be allowed to exercise their trading efforts unfettered? On the other hand, Government assistance can be invaluable when available on the spot, and when it is placed freely at the disposal of manufacturers' overseas representatives. I do not know whether the author intends his scheme to cover all classes of engineering products. My experience is confined to heavier machinery, which calls largely for carefully trained labour in handling and erection on site. Looking back on pre-war conditions, I think that many of our troubles in competing for this class of work were due to causes which it is well within our power to remedy. Did not comparatively small firms spread their selling efforts too widely? Where they manufacture the same type of machinery it should be possible for them to come to an agreement to subdivide markets in such a manner as to enable each firm to concentrate the whole of its energies on the particular districts which it intends to develop. Insufficient attention was often paid to the necessity of

finishing off the smallest details, which, in many cases, can be safely left to the erector at home, but which cause infinite expense and delay in districts where it is almost impossible to procure ordinary engineering materials and tools. In such matters, and in the careful testing before shipment, the much-abused inspecting engineer is often a blessing in disguise. Then there is the question of securing suitable men as representatives. A man representing a firm abroad requires to have far greater engineering qualifications than a branch manager at home does. I believe that the average overseas buyer has very little use for a representative who cannot see him through his troubles when they occur; on the other hand, that he is prepared to go out of his way to place his orders with a firm whose representative is not only willing but able to help him in case of breakdown. The difficulty of finding such men is, in my opinion, due to this. I have found that a large number of young engineers who have just the right temperament for this class of work have no sooner finished their college and shops training than they wish to take positions in the selling organization; for the reason that salaries in the lower grade positions of a purely technical nature are so poor as to discourage men of ambition, except what one may term born designers. If it were possible for them to earn a reasonable livelihood as assistants in erecting, designing, and testing departments, not to mention the drawing office, I think we should soon have plenty of men whom we could send out with complete confidence to meet any form of competition that the Germans or Americans put up against us, and that without resorting to such a very elaborate scheme as that proposed by the author. I do not deny the necessity of co-operation, but I do think we can go too far in that direction and be apt to follow the German example too closely, instead of striking out on lines more adapted to the character of ourselves and of our industries.

Mr. A. W. Blake (*communicated*): Any scheme designed to assist British trade abroad should be sufficiently comprehensive to include, not only engineering products, but all other articles of commerce which this country is capable of producing. The weak point, however, in the author's proposals appears to me to be the introduction of so many opportunities to delay and intercept direct and expeditious treatment by manufacturers of the customers' requirements. If all foreign business had to pass through such an official route as is indicated by the diagram on page 371, delay and dissatisfaction would most certainly be the result. As a nation we are often accused of being slow, and several well-known Britishers have from time to time exhorted us to "wake up" and to avoid being so consistently late. The first principle, then, of any new organization should be to secure the utmost dispatch and the elimination of any feature likely to cause delay in dealing with overseas customers' requirements. I would therefore suggest to the author that a comprehensive telephone system suggests a model to work upon for his scheme. Let such new organization as may be established provide all the necessary machinery as effectively as possible by which to switch on the customer to the manufacturer without any loss of time, enabling them to get their business done and ring off as speedily as possible. Such an organization should be made so essential to every overseas trader that it becomes as necessary to him as the telephone has now become to every business house. It therefore appears that an improvement in the author's proposals might be made by cutting out the Central Board of Control with its six sections in the centre of the diagram on page 371, and substitute therefor a body which might be called by any reasonable designation, such as "Federation of British Industries, Commerce Standards Committee," and let this body standardize the best possible methods of overseas business procedure in all its branches, and act in an advisory capacity to facilitate our international and colonial trade, but leave to the manufacturers themselves perfect freedom to conduct their own business.

Mr. T. O. Callender (*communicated*): Although I am in accord with the author as to the inefficient and uneconomical means which were generally adopted by engineering firms in overseas trade prior to the war, I do not agree with the method which he proposes as a remedy. With him, I consider that combined effort is necessary to meet the competition of the powerful companies in Germany and America which we had to meet in pre-war days, whose efforts to secure trade abroad will be greater than ever when business is resumed. I feel that a Committee, especially one whose members are nominated by associations which are not in themselves pushing actively for business, will have no chance against the fighting capabilities of the great manufacturing concerns whom they will have to meet. The author suggests that the actual production of the materials dealt with should be left to individual effort, which should be entirely uncontrolled. But I consider this so great a fallacy that it entirely upsets the usefulness of his whole scheme. The securing of trade abroad is essentially a manufacturers' question, and success will be really attained only when the manufacturers as a body combine and take it in hand as a united effort in which they are all personally and vitally interested. To me it seems unthinkable that business people should imagine it possible for manufacturers to work abroad with a united front when they are fighting each other at home. Foreign trade, to be successful, must have as its basis a prosperous home market, and I am therefore convinced that if any united effort is to be successful in capturing trade abroad it must begin by united action among the manufacturers at home. The Overseas Department of the Board of Trade has on many occasions recently urged manufacturers to form associations for foreign trade. I have on more than one occasion pointed out the uselessness of this action until the Government is prepared to reverse openly the policy of hostility which for years past has been shown to trade associations in this country. Any progress made to this end has, as yet, been very small, but it will have to be a complete and thorough conversion to united effort all along the line, beginning in the home markets, before we have the strong body of business men whose interest it will be to meet successfully our opponents in South America, in China, and elsewhere overseas Till the

home organization of our manufacturers is complete by amalgamation or by strong association, we cannot hope to carry all before us in the markets of the world.

Mr. J. Eck (*communicated*): The author's personal experience in the overseas engineering trade is extensive and practical, and we have to thank him for stating the facts gleaned from his work, while regretting that he has fallen under the influence of the view that a Government department is or can be efficient or effective in trade. The impression is given early in the paper that Germany has governmental or communal trading organization, and Mr. Atkinson supported this by a diagram with the A.E.G. as the radiating sun that might influence a Committee of the House of Lords but which will not stand dissection. If any trading member of the Institution will substitute his own head organization for the A.E.G. in the diagram, he will be able to construct a similar one, with possibly less radii, applicable to his own business connections. The same applies to Mr. Atkinson's other diagram of the Morgan or Standard Oil octopus. What has really happened in Germany was that the A.E.G., by adding American trust-forming knowledge (Rathenau, the head organizer of the A.E.G., gained his business experience in the United States) to the excellent technical and manufacturing methods there existing, formed a group of allied industries making, using, and selling, which with ever increasing capital has created a most serious menace to the other German manufacturers who are outside it. The A.E.G. is more hated and feared in Germany than in this country. The same applies to the General Electric and Westinghouse interests in America. They are a trust of a different but equally insidious character. Both, however, suffer from swelled head and thus give openings for the independent manufacturers to live and in some cases to prosper. The two gigantic trusts (the A.E.G. and the General Electric Company of America) had, long before the war, agreed areas of trading, the A.E.G. leaving the United States alone so long as the G.E.Co. left Continental Europe alone. Let us hope this convention is now broken and that these two giants are free to slay or maim one another. Table 1, the outcome of the author's practical experience, is perhaps the most valuable part of the paper, for it shows the high expense of selling engineering appliances, and we are interested to see to what extent these figures can be modified by Government action. I venture to say none. But when we come to turn-over a great deal can be done. We should receive from the Board of Trade, when that department ceases to belie its name, assistance in the improvement of transit methods and rates, that will get our goods more quickly and cheaply to the consumer; we should have genuine assistance in information and propaganda, so as to increase the reputation and consequent demand for British-made goods; we should have a consular service of British subjects who have had trade experience; and finally financial assistance in enabling us to carry stock to the consumer's door. Personal experience enables me to say that in Australia an adequate stock of well-made suitable goods properly distributed locally will sell at 20 to 25 per cent higher price than the cost of the same articles f.o.b. London plus freight. It is the case of a bird in the hand being worth more than one in the bush. Another bogy is that of not making the goods to suit the local requirements. I verily believe this is part of the German game. The American and German manufacturers do not pander to these so-called urgent necessities; they send live and competent men out who train the local demand to coincide with their own products. We cannot have too good men representing us abroad; they must not only be up to date but must have had extensive home and erecting and operating experiences, so that every trouble is able to be dealt with locally. Such men must periodically spend a few months at home and in the countries of their trade competitors. The home office must be in sympathetic touch with the overseas men, who must feel they have both friends and colleagues there. A proper home office will see that matters of taste as to packing and other minor matters are attended to, that suitable printed matter is available, that confidential data is regularly transmitted, and that the overseas man never loses confidence and pride in the house he represents. Do not let us run away with the idea that any salesman can run a line of goods produced by different factories. A well-known South of England factory was run departmentally to the consternation of their local agents, who found that for one and the same installation the engineer of A department recommended the use of different apparatus from the engineer of B department. It will be worse with independent salesmen. Finally I should like to say: Stick tight to our own weights, measures, and coinage. We have lost most of our Canadian trade by the use of dollar coinage there; and we shall lose heavy percentages of our other overseas trade if we desert our English-speaking Allies and fall into the Continental baited trap of metrical standards of manufacture. By all means as salesmen let us sell according to the desires of our customers, but let us keep our standards of manufacture unimpaired.

Mr. T. Browett (*communicated*): Having had several opportunities of discussing with the author, before publication of the paper, the fundamental principles underlying his scheme, I know that he relies more on individual effort and initiative than on public or State propaganda to rehabilitate and extend British influence after the war. At the same time I cannot help feeling that the introduction of any State influence whatever is a blot upon the scheme. It is true that he has referred to the Government postal service as an instance of successful State organization; but there is to my mind no proof that even the Post Office could not have been run more successfully as a private concern, provided that the necessary funds had been available. It is, however, just on the question of finance that it is conceivable the State might beneficially intervene, provided that sufficient check could be brought to bear on the personnel responsible for the conduct of this department, and on the Government generally, to prevent extreme socialistic influence from gradually asserting itself to such a degree as to wreck the whole scheme. If the carrying out

of any co-operative scheme should prove to be beyond private finance, it would appear that there is no choice but to fall back upon the State, though in my opinion this alternative should be avoided if possible. Let us now consider what will be the position of Germany after peace is declared. Will Germans be as welcome all over the world as in the past, or will sentiment dictate to any marked extent the commercial policy of our colonies and of neutral countries? The memory of the world is very short, and when money-making, or money-saving, enters into a would-be buyer's mind it is astonishing how quickly his action takes a certain line, whether such action is fundamentally right or wrong. Each one seems to allow his actions to be guided by the first impressions and most obvious deductions of the moment, without considering broad principles, or how far his action is either inimical to the best interest of the world or to those of his own country. Still, the whole history of the world contains no such object-lesson as has been instilled into every thinking man by the present war, and I cannot help feeling that the sentiment born of this experience will be far more lasting than any other influence of the past. It will not do, however, to build too much upon sentiment. Whilst admitting the thoroughness of the German mind and propaganda in every sphere, one must remember that this very thoroughness has been rendered possible only by the military training of the population and by the constant emphasis by the State of the duty of obedience to its omnipotence. In my opinion it is not unlikely that the military influence will be less powerful in the future, and that this severely autocratic atmosphere in Germany will undergo a material modification. In any case I would be the last to copy Germany in anything, nor do I consider that the past records of our own country indicate any need for slavish imitation of the methods of any other country. In war it has now been proved that as a nation our people amply possess and are guided by the same traits of character as originally made Great Britain great; and I am convinced that, given a fair field in commerce, the same genius will not be found wanting. In so far as any parliamentary or other official influence can be safely utilized to further the carrying out of any agreed scheme, it must be cultivated, always bearing in mind that a public servant invariably tends to become a public master.

Mr. L. Andrews (*in reply*): Since the main purpose of my paper was to urge the necessity of organizing some co-operative system of selling engineering appliances in oversea markets, it is naturally very gratifying to receive such practically unanimous support of the general principle advocated. Whilst the details of the scheme outlined in the paper were criticized by all who took part in the discussion, I am so thoroughly in agreement with the remarks made by nearly all the speakers that I can only conclude that the apparent criticisms were due to misconceptions of my own views rather than to any actual difference of opinion between my critics and myself.

Replying to Mr. Griffith, I admit that the expression "Board of Control" was an unfortunate one, since it apparently created the impression that I wished to suggest that this Board should be endowed with despotic powers, which was far from my intention.

I cannot understand his question as to why, in providing for a certain amount of Government control, I have not also provided for any financial assistance from the same source. The paper contains at least three distinct references to the desirability of State financial assistance, and two equally definite recommendations against State control. The suggestion that co-ordination might advantageously be directed by a Board consisting of two State representatives and four representatives of private enterprise undertakings, cannot justly be construed as State control.

In suggesting that the scheme outlined in the paper places a wide gulf between the manufacturer and the user, the fact that such a gulf already exists appears to have been ignored. As a matter of fact, it has been demonstrated by actual experience that an organization framed precisely on the lines shown in Fig. 1 tends to bridge this gulf more completely than is, in my opinion, possible by any alternative proposal other than that every manufacturer should have his own office with a large local staff in every distributing-centre, which is obviously impracticable.

In reply to the criticism that the process by which local demands are to be ascertained, reported to the manufacturers and met, is so cumbersome, etc., I can only say that I have received inquiries by telephone in Winnipeg between 5 p.m. and 6 p.m., cabled particulars to my colleagues in London, who have obtained the necessary information from manufacturers in, say, the Midlands, and sent a reply in time to enable me to submit a tender and complete specification to the customer between 8 and 9 the following morning. This has been possible on account of the difference in time between London and Winnipeg, since London works whilst Winnipeg sleeps. It was, however, mainly due to the fact that in the so-called "cumbersome and unwieldy" organization intervening between manufacturer and user a perfect understanding existed between the distributing centre and central office, which ensured the inquiry and reply being transmitted promptly and intelligently.

Mr. Griffith's suggestion, that the district salesmen referred to in Fig. 1 should be expert engineers, would not, I am afraid, be practicable. The method we adopted at Winnipeg was found to be entirely satisfactory. The sub-district salesmen or travellers, of which we had four, were not qualified engineers but were men having sufficient general engineering knowledge to be able to send in to the Winnipeg office intelligent particulars of all engineering inquiries they came across on their rounds. Three qualified engineers were located at the central district office, each of whom was, respectively, a specialist in different branches of engineering. These engineers dealt with inquiries as received by telephone or mail, either direct from users or sent in by the sub-district salesmen. The latter returned to the office for a few days at frequent intervals to report fully upon their experiences and to be primed with fresh information for their next round of visits. When a number of important inquiries from any particular district appeared to justify

it, one of the engineers would follow up such inquiries by a round of visits. To have employed these engineers in scouring the 160,000 square miles of territory, worked from this one centre, in search of prospects, would have been most inefficient. This was the work of the sub-district salesmen, who were better qualified for it since they each had an established connection with buyers in their respective sub-districts.

I entirely agree with Mr. Madgen that there is no foundation for the popular fallacy that British manufacturers are less willing to vary their designs to meet the genuine requirements of their oversea customers than are manufacturers in other producing countries. My own experience has been that engineering manufacturers in this country are invariably ready to make changes when it is clearly demonstrated that such are desirable. I can imagine nothing more detrimental to oversea development than that manufacturers should be constantly changing their designs to meet the, usually, unconsidered recommendations with which they are constantly being flooded from all parts of the world. The sole reason American and German manufacturers have acquired the reputation of adapting their designs to suit the requirements of individual users, is that their better organized system of distribution enables them first to study what is best for the user and to standardize their production accordingly, and to follow this up by educating the user to demand what they make. I also agree that the buyer wants and, in fact, insists upon dealing only with the man who is competent to discuss the engineering features of the plant under consideration; but he is equally insistent that the same man shall be available to assist him with advice in installing and starting the plant, and above all, he requires assurance that the firm with whom he places his contract—whether it be the manufacturer or the local merchant does not concern him—shall be close at hand during the life of the plant to render assistance when necessary. I have, on more than one occasion, met oversea buyers who have boasted that by visiting England and purchasing plant directly from manufacturers they have saved enough to pay the expenses of the trip, and a few months later these same buyers have told me that they would gladly sacrifice far more than their supposed original saving in initial cost to have purchased the plant from a local firm to whom they could apply for assistance when in trouble. I have also known of cases where buyers have replaced British-made plant, which had given them complete satisfaction during the few months it had been in use, by American-made plant, for no other reason than that the local firm from whom they had purchased the original plant had ceased to represent the British manufacturer. If the proposed co-operative selling organization did nothing more than assure oversea buyers of continuity of local representation, in place of the constant changes that have occurred in the past, it would, by this means alone, have a most salutary effect upon this country's oversea trade.

I feel particularly indebted to Mr. Atkinson for his strong support of the co-operative selling movement. I entirely agree that if it is possible to overcome the inherent difficulty he refers to, of getting British engineers to sink their individualistic tendencies, the best possible solution of the co-operative selling problem would be that resulting from the joint action of several associations covering allied engineering trades. My own oversea experiences entirely endorse Mr. Atkinson's remarks, that if British engineering manufacturers could but be induced to participate in some properly organized co-operative selling scheme they would all increase their individual businesses beyond anything they have ever imagined.

I agree with Mr. Newlands that had the co-ordination of this country's industry been complete before the war, the creation of Area Boards of Management for the production of munitions would have been unnecessary; and by the same token, if perfect co-ordination can be secured by the aid of trade associations there will be no need for any such decentralized purchasing agency in connection with oversea distribution.

Mr. Rosling appears to have been the only supporter of the at one time popular creed that British pre-war methods of conducting oversea trade were "good enough." Referring to his criticism of my terminology, I should have thought that the "impossibility of any one nation being able to attain supremacy over other nations in all industries," was sufficiently self-evident to have justified the statement that it is an "axiom" rather than a "postulate," but I am quite prepared to accept his ruling upon this matter.

As Mr. Selwyn Grant points out, the distribution of expert knowledge to a large number of producing and distributing centres is a real difficulty. It is obvious, however, that a properly constituted central organization will be in an infinitely better position to cope with this difficulty than a very large number of individual manufacturers working without co-operation can possibly be.

I agree with Mr. Kingsbury that, paradoxical as it may appear, the engineering industry has undoubtedly suffered from the commercial pre-eminence of Great Britain, owing to the fact that export trade has been conducted mainly through the medium of shipping merchants. Mr. Foyster also touches upon the same point, and the original draft of my paper contained the following reference to it:—"Oversea trade through the medium of City shipping houses is entirely satisfactory so long as it is confined to staple products, but when applied to the sale of engineering products it fails to keep the buyer advised of the changes and improvements that are constantly being made by all British manufacturers, and fails to keep the latter informed of the buyers' ever-changing requirements." With a view to counteracting this evil, there is at present a tendency, which is in my opinion regrettable, for engineering manufacturers to short-circuit the merchant and deal direct with users. If the statement is accepted that "co-ordination may be defined as the most efficient utilization of all existing and potential factors of production and distribution," one of the first duties of the co-ordinating body, however constituted, should be to consider how the most efficient use can be made of the very great asset Great Britain possesses in her quite exceptional connection with oversea markets

through shipping merchants. The present deficiency as regards technical knowledge should be made good by arranging that all oversea merchants associated with the co-operative scheme should have their oversea staffs supplemented by the addition of a number of qualified engineers who would respectively be specialists in different branches of engineering (see Appendix II). These engineers might be supplied by the respective trade associations, and would therefore be representative of the entire industry and not of any individual firm or firms.

Mr. Broadbent's reference to the manner in which British export trade is handicapped owing to the lack of co-operative support on the part of shipping and railway companies, is a valuable contribution to the discussion. It is a striking example of the effect of German co-ordination for the benefit of the community versus British individualism, and is a matter that should most certainly receive the attention of the proposed co-ordinating board.

Mr. Williams suggests that I propose to take profits from shippers; on the contrary, my suggestion was that shippers' average pre-war rate of profit should be guaranteed them and that they should be assisted to make much bigger profits, of which excess profits they should retain one-third whilst the remaining two-thirds should be applied to meeting the cost of enabling them to make increased profits. I am entirely in disagreement with his proposal that any co-operative scheme for distributing engineering products should also include all branches of commerce. In the first place, one of the biggest demands for engineering appliances in oversea markets is for the equipment of industrial factories for producing, locally, products that are necessarily competitive with similar products made in this country. It is obvious that a selling organization attempting to sell, say, British electric motors to a factory for the production of, say, boots and shoes, would be greatly handicapped if the same organization were also selling boots and shoes of English make.

Mr. Cowan objects to my scheme on the grounds that it tends to separate production and distribution, and then goes on to explain how he is acting as a connecting (but nevertheless intermediate) link between manufacturers and users in a particular territory. From what I know of Mr. Cowan's work, I consider that he is doing, in a comparatively small market, precisely the work that I suggest should be carried out by a co-operative organization in all oversea markets. He has spent sufficient time in the distributing area that he is dealing with to establish a connection with all of the principal buyers of the products he is handling and to know their requirements, and is consequently in a position to pass this information on to the manufacturers concerned. If all oversea markets and all engineering products were handled in an equally efficient manner, without overlapping, there would be no need to discuss the question of improving oversea distribution. However, to compare Mr. Cowan's work with the world-wide scheme under discussion is, to borrow Mr. Blake's analogy, like comparing a single-line two-instrument telephone installation with the exchange system of a large city. The individual direct connection has undoubted advantages for its extremely limited sphere of usefulness, but to suggest that the exchange system should, consequently, be replaced by a multiplicity of direct lines would obviously be absurd.

Captain Slacke's proposal that the Council of the Institution should combine with other engineering Societies and Associations in forming a committee to advise upon the problems of oversea trade, is an excellent suggestion which I trust will be acted upon.

Mr. Allcock gives an interesting résumé of some of the alternative methods of developing oversea trade that have been tried, and with the majority of his conclusions I agree. His objection, however, that the combination of the expert technical ability of the manufacturer's works-trained engineer with the local knowledge and connection of the merchant enables the latter to build up his business and goodwill at the expense of the home manufacturer, savours too much of individualism. His later remarks—particularly his reference to my quotation from Naumann—appear in fact to show that he is a pronounced individualist. I must confess that I am quite unable to understand or appreciate what it is that makes any man apparently willing to ignore his country's welfare, his firm's welfare, and even his personal welfare, if he can only retain his "cherished individualism." It is surprising to find so enthusiastic and able an advocate of the metric system failing to recognize how much greater is the hampering influence of individualism than is the so-called "obsolete system of English weights and measures."

Replying to Mr. Bosworth, the weak point I referred to in "private enterprise control" was not so much the necessity of making profits, as that this necessity was obviously liable to lead to the welfare of the community being sacrificed to the quite legitimate profit-earning aims of the private-enterprise controlling organization. I agree that the necessity of profit-earning is the best incentive to efficiency, and that the absence of this necessity is a very real objection to any form of State control.

It is entirely contrary to my own experience that oversea buyers prefer to deal directly with manufacturers at home rather than with so-called third parties or local merchants. Shortly before leaving Winnipeg I was told by a buyer of heavy engineering plant that he had refused to consider the tender of a British firm who had previously supplied him, through a local house, with practically identical plant to that required at the time, and whose price in the present case was quite satisfactory—his sole reason for refusal being that the firm in question had ceased to be represented by a local house in that particular distributing centre. This is merely one example of many indications received that oversea buyers will not do business with British firms who have not either a local branch of their own, or alternatively are adequately represented by a substantial firm of local merchants. This is not surprising when one remembers that few English buyers would be willing to purchase machinery from an American manufacturer who was not represented by a substantial

house in this country. A mere string of names of well-known American manufacturers on the office door of an individual representative of such firms would not procure much business in this country, and yet this constitutes the sole representation many well-known English manufacturers have in oversea territories where conditions are in other respects very similar to what they are at home.

I am also unable to agree that "the purchaser would be unwilling to buy nameless goods." With a view to endeavouring to ascertain to what extent the names of well-known British manufacturers of engineering appliances assisted in creating a market for such products in oversea territories, I tried the experiment of introducing some products under the names of well-known British makers, and others under the name of the local selling organization—the maker's name being entirely suppressed in the latter case. So far as I was able to determine, it made little or no difference whether a great feature was made of the maker's name, or whether it was entirely suppressed. The mere statement that the product is "British made" is of far greater selling value than any individual maker's name.

I entirely agree it is most desirable that manufacturers should concentrate on the production of a limited range of sizes and types of, say, electric motors and other appliances, instead of each individual manufacturer endeavouring to cater for a large variety of different sizes as at present. A properly developed scheme of co-operative selling should tend gradually to achieve such result.

Replying to Mr. Kaula, my opinion is that the central organization, co-ordinating oversea distribution, should deal with all branches of engineering, though in the case of heavy engineering, such as bridge-building, for instance, the assistance it would be possible to render would be of a very limited nature. I entirely agree with his remarks respecting the necessity of choosing men of the highest possible engineering qualifications as oversea representatives. American producers are keenly alive to the importance of employing highly qualified distributing engineers for both home and export trade. Mr. Samuel Insull, President of the Commonwealth Edison Company, in an address to the Investment Bankers Association in 1913 said: "I think, if I had to choose between first-class construction engineering and first-class selling engineering, I would choose first-class selling engineering."

Mr. Blake's anticipation that the transmission of inquiries and the execution of orders through the medium of oversea distributing centres and a central office in London would be liable to cause delays, is in my opinion without foundation, as I have endeavoured to show in replying to Mr. Griffith.

I entirely agree with Mr. Callender that, in many respects, an ideal condition will be reached when all British manufacturers of engineering appliances can be induced to sink their individualistic tendencies so far as to agree to combine in providing for the sale of their joint products in both home and foreign markets. It appeared to me, however, and does so still, that the prospect of effecting so close a union is somewhat remote, whereas the necessity of immediately organizing some form of co-operative selling in oversea markets is so important that the matter cannot safely be deferred in order that an attempt may be made to achieve what I fear will prove to be impossible at present. I agree that "the securing of trade abroad is essentially a manufacturer's question," and it should unquestionably be left to them to handle if they can show that they are doing so efficiently; but it is also a national question of the very greatest importance, since its efficient handling, or otherwise, affects every member of the community. The latter point is frequently overlooked by many manufacturers who speak of oversea trade as if it concerned them alone.

My own experiences endorse Mr. Eck's that, not only in Australia but also in Canada and other oversea markets, at least 20 per cent higher prices can be obtained for deliveries from stock than for direct shipment from home; in fact, many appliances such as electric motors of less than 50 b.h.p. can rarely be sold unless delivered from stock.

Mr. Browett's warning that "it will not do to build too much upon sentiment" should not be ignored. Germany is doubtless expecting, and hoping, that British manufacturers and distributors will be so confident that the close alliance created by the war will be followed by such a strong trade alliance as to make it unnecessary to take other steps to guard against enemy competition. It is just because sentiment is at present so strongly opposed to anything German, that every effort should be made now to take advantage of such a favourable opportunity for improving oversea trade. There has never before been such a unique opportunity, nor is it likely that such will ever occur again.

TELEPHONE EXCHANGE TRANSFERS AND THEIR ORGANIZATION.

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(*Paper received* 25 *October*, 1917; *read before* The Institution 24 *January*, *before the* Manchester Local Section 29 *January*, *and before the* Newcastle Local Section 11 *February*, 1918.)

Précis.

I. Introduction.
II. Line plant considerations.
III. Methods of effecting transfers.
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I. Introduction.

The development of the art of telephony necessitates frequent re-arrangements and modifications of plant, and an operation of first magnitude to the telephone engineer is that of the transfer of a large group of subscribers' lines from an exchange or exchanges in operation to another exchange prepared to receive them.

To transfer the actual switching apparatus, intact, from one position to another is impracticable without causing considerable dislocation of the telephone service, and such an operation need not be considered because the early obsolescence of telephone exchange plant usually dictates the displacement of the old plant by modern equipment. Therefore a transfer is generally accompanied by a change in the system of working, also by displacement of certain overhead by underground plant, or by an extension of the existing underground system. These changes introduce complications in the extended series of operations associated with the transfer.

The change of system most frequently to be dealt with in this country is from magneto to central battery working, with lamp signalling, and the work associated with such cases has become more or less standardized.

The scope of this paper has been confined as far as possible to operations for actual transfer, but consideration has also been given to engineering processes which, although not necessarily essential to the transfer, customarily accompany the work.

It has been assumed that the whole of the new exchange plant is satisfactorily installed and has been tested out as provided for in the specification under which it has been erected.

Broadly considered, transfers may be effected in three ways, as follows:—

(*a*) By transferring each line independently,

(*b*) By transferring the subscribers in groups,

(*c*) By transferring the whole of the lines at one operation.

Method (*a*) possesses certain commendable features, but traffic considerations unfortunately preclude the adoption of this method which necessitates difficult and costly traffic arrangements modified at intervals as the transfer progresses.

Method (*b*) has similar, although less serious, objections to (*a*), the traffic and operating arrangements requiring modification after the transfer of each group is accomplished.

Method (*c*) is the one usually adopted. From a traffic point of view, difficulties are reduced to a minimum; the actual operation can be carried out expeditiously—the time taken being a matter of seconds—and a period can be selected for the change when it is known that the traffic will be at a minimum and when the least possible interruption to the service will ensue.

II. Line Plant Considerations.

The subscribers' lines to be diverted must be dealt with in such a way as to render each line available for simultaneous connection to the new exchange when the circuit is severed from the old. The relative situations of the old and new exchanges and the lay-out of existing line plant will largely influence the arrangements for the transfer.

It has been assumed that the lines are led into the exchange by means of underground cables. It will be necessary to install new cable plant from the new exchange to one or more suitable points where the lines affected may conveniently be tapped. These points may be situated as follows:—

(*a*) On the existing main underground routes;

(*b*) On the existing overhead lines;

(*c*) At the old exchange.

Existing conditions will to a large extent govern the line-plant arrangements to be adopted in effecting a transfer, but four typical examples have been selected and are shown in Fig. 1.

(*a*) *Lines teed underground.*—Fig. 1 (*a*) exemplifies one of the simplest arrangements. New cable plant is provided between the new exchange and a point "T" conveniently located on the existing cable system at which the whole of the lines are available. At this point teed connections are made, thus linking the circuits to the main distributing frame of the new exchange. Although one teeing point only is shown in the example, several points may be selected according to the lay-out of the underground plant.

(*b*) *Lines teed underground and overhead.*—It may be required to open up one or more new distributing points on the open line system concurrently with the

transfer. Fig. 1 (*b*) illustrates such a case, where, in addition to a point T situated in the underground cable system, teed connections are also made at points (marked Y) on the open line routes.

Lines teed at old exchange.—Generally speaking, the tapping of the existing lines at the old exchange is undesirable, in consequence of the difficulty in avoiding interruptions of the working lines when cutting them out of the old premises after the transfer. There may be instances, however, where this measure may be necessary with some, if not all, of the lines to be services until they are transferred, increases with the distance between the two exchanges and unfortunately precludes the adoption of this method in every case.

The arrangement is illustrated in three stages in Fig. 1 (*c*). In the first stage the existing underground plant is shown associated with the old exchange. New cable plant is permanently installed between the new exchange and a point (or points) situated upon the existing underground system (marked *x* in the diagram), and cable accommodation must also be available between the same points sufficient to accommodate

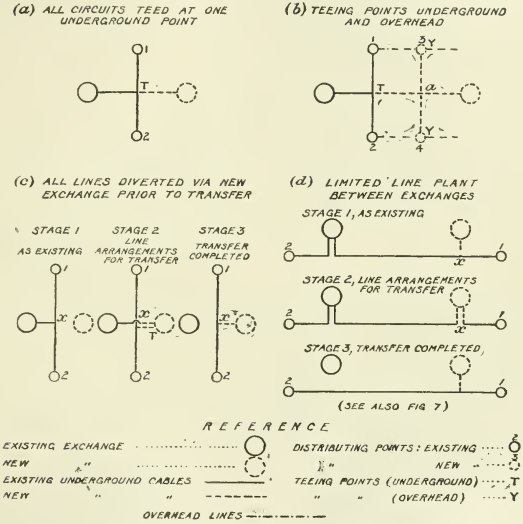

(a) ALL CIRCUITS TEED AT ONE UNDERGROUND POINT
(b) TEEING POINTS UNDERGROUND AND OVERHEAD
(c) ALL LINES DIVERTED VIA NEW EXCHANGE PRIOR TO TRANSFER
STAGE 1 AS EXISTING
STAGE 2 LINE ARRANGEMENTS FOR TRANSFER
STAGE 3 TRANSFER COMPLETED
(d) LIMITED LINE PLANT BETWEEN EXCHANGES
STAGE 1, AS EXISTING
STAGE 2, LINE ARRANGEMENTS FOR TRANSFER
STAGE 3, TRANSFER COMPLETED
(SEE ALSO FIG 7)
REFERENCE
EXISTING EXCHANGE
NEW "
EXISTING UNDERGROUND CABLES
NEW " "
OVERHEAD LINES
DISTRIBUTING POINTS: EXISTING
" NEW
TEEING POINTS (UNDERGROUND)
" " (OVERHEAD)

FIG. 1.—Examples of Exchange Transfers with varying Line Plant Conditions.

transferred in order to avoid teeing at some less suitable point outside.

(*c*) *Lines diverted via new exchange.*—If the distance between the old and new exchanges is not excessive, it may perhaps be an economical proposition to divert the whole of the subscribers' lines into the new exchange and thence to extend them temporarily to the old exchange. In this case the point at which the lines are teed will be situated at the main distributing frame of the new exchange. This arrangement possesses decided advantages and greatly simplifies and facilitates the operations to be performed both at the transfer and afterwards; but the cost of provision of the circuits between the old and new exchanges, for the purpose of accommodating the subscribers' the whole of the circuits until they are transferred. The circuits are then diverted at point *x* through the permanent cables to the new exchange, where they are cross-connected on the main distributing frame and conveyed to the old exchange in the most economical manner possible, existing plant being utilized between point *x* and the old exchange. It may be practicable to utilize some of the spare cable plant provided for future development between the new exchange and point *x* and so save the cost of providing entirely new cables.

This arrangement is a highly satisfactory one and possesses the following important advantages:—

(1) Elimination of external teeing points and consequent immunity of faults from that source.

(2) Alterations to working circuits after transfer reduced to a minimum.

(3) Severance of the old from the new plant automatically at transfer, and possibility of trouble arising from old plant left in circuit removed.

(4) All tees assembled at one perfectly safe point, affording facilities for their prompt removal.

(5) Transfer operation conducted wholly in the apparatus room of new exchange.

(6) Cost avoided of possible renewals to old plant to be afterwards discarded.

(*d*) *Arrangement when line plant between exchanges is limited.*—When the distance between the old and new exchanges is considerable and the circuit capacity of the line plant is necessarily limited, it may be advisable to have recourse to the method of transfer illustrated in Fig. 1 (*d*). For explanatory purposes the subscribers' lines may be regarded as being divided into two equal groups, say, A and B, these groups being respectively served from distributing points Nos. 1 and 2 in the diagram. Group A comprises those lines which pass by or near to the new exchange on their way to the existing exchange, and group B those lines serving subscribers situated on that side of the existing exchange remote from the new one. Arrangements are made such that the limited line plant between the two exchanges serves—

(*a*) before the transfer to carry those lines comprised in group A;

(*b*) after the transfer to carry those lines comprised in group B.

This necessitates the lines in group A being diverted before the transfer so that they pass through the new exchange. After the transfer, group B of subscribers' lines must remain passing in and out of the old exchange until cut out by subsequent re-arrangement of the underground plant.

In the diagram, stage 1 shows the arrangement existing before the transfer, also the new exchange with new underground plant installed to a suitable point (marked *x*) on the existing underground system. Stage 2 exemplifies the diversion of the lines comprised in group A through the new exchange. Stage 3 shows the transfer completed, the underground plant immediately affected by the closure of the old exchange adjusted, and the discarded plant removed.

The following disadvantages are inseparable from this method :—

(*a*) The operations associated with the elimination, after the transfer, of the working lines from the discarded exchange and the re-arrangements of underground plant which ensue in that vicinity, are considerable.

(*b*) The operations required to effect transfer are increased in number.

(*c*) Risk of interruption to the service in consequence of the complicated nature of the arrangements is inevitable.

(*d*) Fault testing and localization during the continuance of the temporary arrangements are hampered.

Four typical schemes for transfer, in so far as line plant is concerned, have been dealt with. Although it is advisable that the line-plant arrangements should be simplified as far as is practicable, circumstances do not always permit of one arrangement only being employed, and in some cases a combination of two or more different arrangements are necessarily embodied in one scheme.

III. Methods of Effecting Transfer.

The particular means adopted in accomplishing a transfer may of course vary according to the circuit arrangements which obtain and with the design of the apparatus concerned, but it is not possible in this paper to describe the various arrangements of circuits and apparatus which may be necessary. The example given in Fig. 2 may, however, be taken as a fairly typical case. The diagram shows that portion affected of the electrical circuit of one subscriber's line only, prepared for transfer from a magneto to a central battery exchange.

The actual transfer operation, in so far as one line is concerned, is perfectly simple, but, when the whole of the lines concerned are taken into account, the number of individual operations to be carried out may be very large indeed, running into many thousands.

The problem is to disconnect all the working lines from the old exchange and, simultaneously, to connect them for immediate service to the new exchange. Upon reference to the diagram it will be seen that if the heat coils at the old exchange are withdrawn, the exchange line will be disconnected there, and that if the insulating separators shown between the spring contacts of the cut-off relay situated at the new exchange be thereafter removed, the circuit will be at once thrown on to the new equipment, leaving the portion of the line between the teeing point and the old exchange as a tee upon the new circuit.

It is essential that the withdrawal of the separators from the cut-off relays should not be attempted until all the heat coils at the old exchange have been removed; failure in this respect will result in the circuit being closed through the indicator winding at the old exchange and the calling lamp at the new switchboard actuated.

The means adopted for the extraction of the heat coils must be such that the whole are removed within the space of a few seconds. This can best be effected by means of two fairly strong tapes threaded behind the coils from top to bottom, one on each side of the strip, the two ends at top and bottom being bound together. If the bound extremities of the tape be held, one in each hand, a fairly smart and extended pull will cause all the heat coils in the strip to spring out of their clips. The possibility of faults being caused by displacement of springs or carbon blocks of arresters during withdrawal of the heat coils should be guarded against. If the protectors are of the earthing type, precautions are necessary to prevent the springs making earth when the heat coils are withdrawn. To avoid possibility of earth faults appearing during the period intervening between the transfer operation and the removal of the tees, the whole of the carbon blocks and mica separators may be withdrawn, dusted, and replaced before the tapes are fixed.

Fig. 3 gives details of the Western Electric Company's

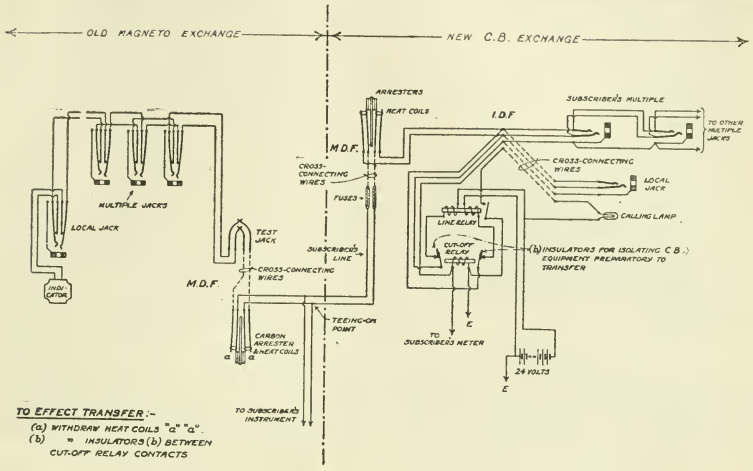


FIG. 2.—Circuit Arrangements for Transfer of Subscriber's Line from Magneto to Central Battery Exchange.

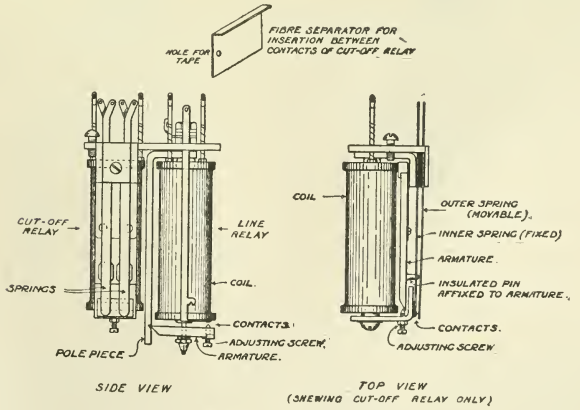


FIG. 3.—Combined Line and Cut-off Relay with Fibre Separator for separating Relay Contacts.

type of combined line and cut-off relay and also shows a convenient form of thin vulcanized-fibre separator for insulating the relay contacts. Suitable means for quickly removing the separators are illustrated in Fig. 4.

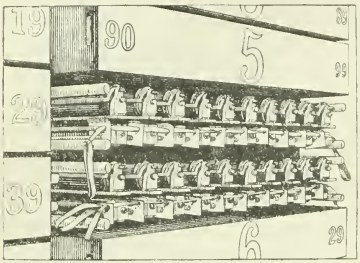


FIG. 4.—Two strips of 10 cut-off relays with separators in position prepared for withdrawal.

Two relay mountings of 10 relays each, with fibre separators in position, are shown. A length of tape is passed successively through holes punched in the 10 separators of each mounting, and loops are provided at each end. The 10 separators may be withdrawn simultaneously by smartly drawing forward the tape whilst the loops at its extremities are held one in each hand. If several bays of relays are required to be dealt with simultaneously, the time expended in performing the operation may, if considered desirable, be materially reduced by forming the loops in the ends of the tapes of one bay of relays round two stout bamboo rods placed vertically one on either side of each bay. The two bamboo rods may be braced together by two horizontal cross-pieces so as to form a rigid framework. The whole of the insulators in the relays of one bay may then be withdrawn simultaneously by firmly grasping the cross-pieces and pulling the frame smartly forward, care being taken to maintain the bamboos in a vertical position. If a smart transfer be desired, some method of this description may, with care, be successfully adopted. It is, however, doubtful whether the resulting reduction in time justifies the increased risk of confusion which accrues from the adoption of measures of this character. Should one or more of the separators fail to leave the contacts successfully, the whole bay may be delayed, whereas if each strip of 10 relays be treated independently, a failure will affect 10 relays at the most.

Where the protectors are provided with additional springs in order to admit of the insertion of the test plug without first removing the heat coils, another method for transferring the lines to the new equipment offers itself. Instead of separating the new from the old equipment at the cut-off relays, wooden insulating plugs may be inserted between the springs provided in protectors of the type in question, so insulating the teed lines from the new exchange plant. The withdrawal of these plugs will serve the same purpose as the withdrawal of the separators from the cut-off relays. A cord threaded through holes bored in the insulating plugs provides means for their simultaneous extraction. Fig. 5 gives sectional details of the type of protector referred to, and also shows insulating plugs inserted in readiness for withdrawal.

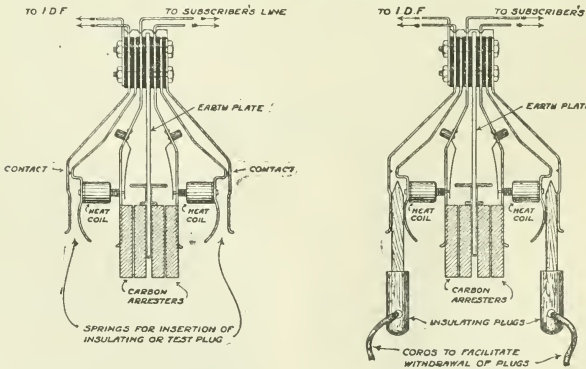


FIG. 5.—Protective Device for Telephone Exchanges, with extra springs to obviate removal of heat coils before insertion of test plug.

This method has the advantage that it avoids disturbance of the cut-off relays; also, during the time the preparatory work is in hand, the heat coils may be kept in position from the outset, the new equipment being completely isolated by the wood wedges from the portion of the circuit external to the new exchange. If it be required to test any line with the new exchange strip. The whole of the plugs in position in one vertical strip may then be withdrawn by smartly pulling forward the bamboo pole, care being taken to keep it vertical.

Fig. 6 shows diagrammatically the conditions fulfilled for transfer where lines have first been diverted through the new exchange, service being meanwhile

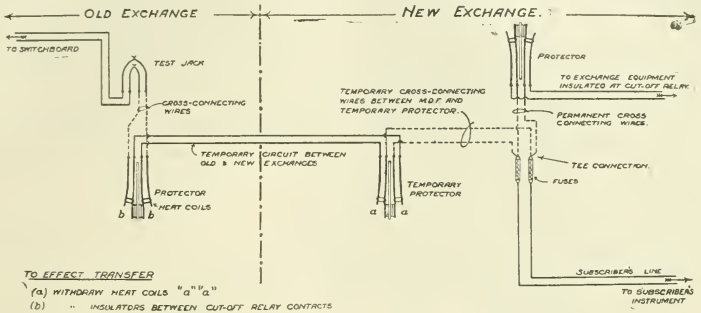


FIG. 6.—Circuit Arrangements for Transfer where all lines are first diverted through New Exchange.

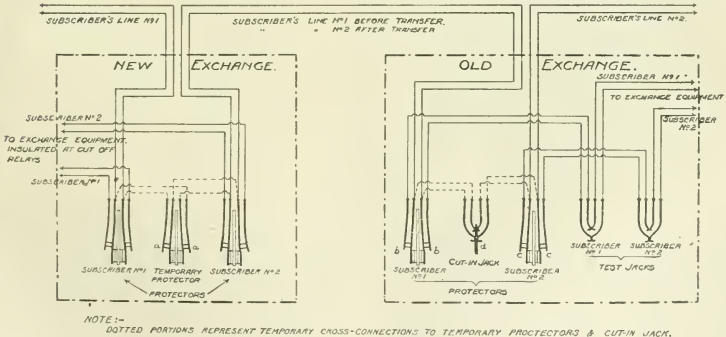


FIG. 7.—Method of Transfer with Limited Line Plant between New and Old Exchanges. Arrangements for Transfer complete.

equipment, the insulating plugs associated with the respective line may be removed (sufficient slack being left in the cord to admit of this being done) without removing the heat coils. If desired, the removal of the insulating plugs may be speeded up by passing the looped ends of the cords at the top and bottom of each section of protectors forming one vertical strip round a stout bamboo pole placed vertically in front of the maintained on temporarily provided circuits between the existing and new exchanges. The arrangements are precisely similar to those shown in Fig. 2 except that in this case the tee connection is made on the exchange side of the main frame fuse and a temporary protector interposed at the new exchange apparatus room, as shown.

Reference has already been made to a means of

transfer which may be adopted when the line plant available between the new and existing exchanges is insufficient to admit of the whole of the circuits being teed into the new exchange. The method involves additional apparatus being fitted temporarily at the new and old exchanges and is illustrated in diagram form in Fig. 7. The diagram shows the necessary arrangements for transfer of two exchange lines only, one being situated on the side of the old exchange remote from the new and the other on the side of the new, remote from the old exchange. Any even number of subscribers may of course be treated in this way, but it is not desirable that the number should be greater than is necessary to admit of the requisite accommodation being afforded by means of the available line plant.

Between the protectors of lines Nos. 1 and 2 at the old exchange, a jack is interposed and is connected by short lengths of cross-connecting wire to each pro-

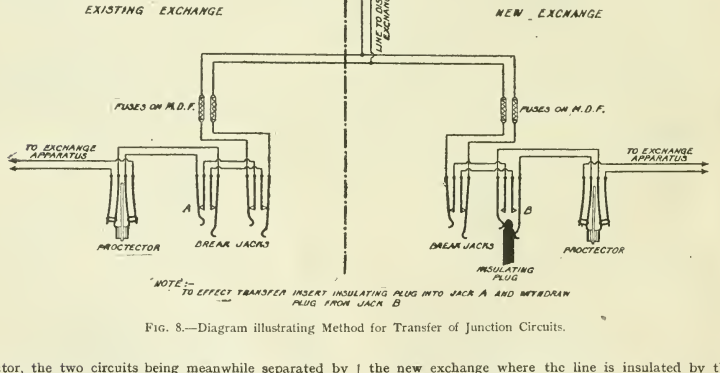


FIG. 8.—Diagram illustrating Method for Transfer of Junction Circuits.

tector, the two circuits being meanwhile separated by an insulating plug inserted between the springs of the jack. At the new exchange the line of subscriber No. 1 is cut in and out of the main frame equipment, service being maintained via a spare or temporarily fitted protector connected as shown, the heat coils being in position. The separators inserted between the contacts of cut-off relays and the fuses on the main frame are not shown in the diagram. To effect transfer, the following operations are necessary:—

(*a*) Withdraw heat coils from protectors of lines Nos. 1 and 2 at existing exchange, thus disconnecting both lines from the existing exchange equipment.

(*b*) Withdraw heat coils of temporary protector at new exchange, thus isolating the section of circuit between the two exchanges formerly used for line No. 1.

(*c*) Withdraw insulating plug in specially provided jack at old exchange, throwing line No. 2 on to its proper protector at the new exchange by means of the same pair of wires previously in use for subscriber No. 1 between the two exchanges.

(*d*) Withdraw separators not shown in the diagram, in cut-off relays at new exchange.

This completes the transfer operation. The temporary protectors and wires at the new exchange may then be removed, the line cut out of the old exchange, and the old protectors and temporary jack recovered.

Junction circuits.—To provide testing and other facilities two break jacks are permanently included in the circuit of each junction line at the exchange. The jacks associated with the whole of these circuits entering an exchange are usually mounted together in a convenient position on the main distributing frame. Fig. 8 shows diagrammatically the break jacks utilized in the transfer of junction lines. One line only is shown with the final arrangements for transfer completed. From a convenient point on the line, a tee is conveyed into the new exchange where the line is insulated by the insertion of an insulating plug in one of the break jacks. The insertion of a similar plug into the jack at the existing exchange (or alternatively the withdrawal of the heat coils) and the withdrawal of the plug at the new exchange will have the effect of disconnecting the line from its existing exchange and throwing it on to the new.

IV Preparatory Line Work.

Existing plant renewals.—Although the line plant of a magneto system may have been maintained in a thoroughly satisfactory manner, there may exist possible sources of trouble which, although unnoticeable with the magneto system, may become apparent when central battery conditions are introduced, unless remedial measures are taken. The central battery system demands that the line plant should be maintained with a relatively higher standard of insulation. Fleeting

troubles such as intermittent earths, contacts, and short-circuits of but little moment in the case of the magneto system must be eliminated. Therefore, when the change is from magneto to central battery it is advisable that the open line plant be overhauled and such weaknesses removed.

Fugitive line faults are not readily revealed by electrical test, and examination throughout of the existing open line plant which is to be utilized in the new central battery system may be advisable.

In order to ascertain which lines need improvement in insulation, preliminary insulation tests may conveniently be made from the old exchange. These tests are described in the section dealing with " Preparatory Work at Old Exchange."

TRANSFER FROM ..... TO .....
EXCHANGE

CABLE DISTRIBUTION SCHEDULE.

Particulars of lines served by D.P. No.....
D.P. Address .....
Main Cable Code or No.....

Numbers				Subscribers'			
D.P. Pair	Main Cable Pair	Arrester		Number		Name	Address
		Bar	Pair	Existing	New		

FIG. 9.

New line work.—In view of the peculiar troubles to which open lines associated with a central battery system are likely to give rise, it is desirable that, so far as is economically possible, the proportion of open line plant should be limited. Therefore, when replacing a magneto by a common battery system, expense in substituting underground for heavy open lines is usually justified. Advantage may at the same time be taken of the opportunity to provide for future development. The new plant may take the form of extensions of an existing underground system, or an entirely new scheme of underground work may be embarked upon for an exchange area previously served wholly by overhead means.

Where the establishment of a central battery system is justified, it is generally economical to arrange an underground system with distributing points from which the subscriber's services are completed by means of small distributing cables underground or short sections of open wire. In this way the mileage of open line is minimized.

The work of installation of new ducts and cables may proceed while the exchange building is in course of preparation. The work should be so timed that the external cables are completed by the time the new main distributing frame is ready for use. The main cables may then be extended thereto, terminated, tested, and numbered out, and connected up to the main frame equipment.

Shunting lines into new exchange.—Each jointer responsible for shunting the lines to the new exchange requires to be provided with—

(*a*) Cable distribution schedule (see Fig. 9) for each distributing point allotted for his attention.

(*b*) Cable distribution diagrams of the cables with which he has to deal as they exist.

(*c*) Cable distribution diagrams of the cables concerned as they are required to be finally.

(*d*) Direct telephone connection from the teeing point to the apparatus room of the new exchange.

At each point where the lines to be transferred are to be cut into for the purpose of making the tee connections, each cable must be opened out, and for each pair of wires the following procedure is recommended.

(*a*) Select pair of wires and slip back paper sleeves, thus exposing twisted joints.

(*b*) Connect loop to jointer's portable telephone set and listen.

(*c*) If, after challenging, line proves to be disengaged, disconnect one wire of loop and give short ring on exchange side (this avoids calling the subscriber unnecessarily).

(*d*) Ascertain from answering operator exchange number of line under test and, if more than one exchange is served by wires in the cable being dealt with, the name of the exchange also.

(*e*) If no reply received, and line tests spare, then, assuming no spare connections are being provided until after the transfer, the spare ends may be left disconnected and placed on one side. If a working line the teed connection is made by jointing to the appropriate pair of wires leading to the new exchange.

(*f*) Replace paper sleeves and label them with exchange number.

(*g*) Periodically advise test clerk at new exchange of lines dealt with.

After the jointer has dealt with the whole of the lines, the joint or joints may then be plumbed up or, if this course is impracticable, secluded from the atmosphere by other suitable means.

Making tee connections.—The provision of tee connections in association with the transfer of a large exchange is a matter of considerable importance. The manner in which the connections are first made and afterwards maintained has considerable influence upon the success with which a transfer is accomplished. An unsystematic arrangement of indifferently made tees will undoubtedly be an endless source of trouble and anxiety to the engineer controlling the operations.

For a large transfer, the number of tee connections to be made may be considerable; it may be impracticable to avoid making a large number of tees at one

or more points on the underground cable system and to distribute them over a number of lesser points; several large cables may be involved at one point and, as the number of pairs of wires to be dealt with increases, so are the difficulties multiplied.

The small gauge wires (6½, 10, and 12½ lb. per mile) on large cables (600 and 800 pairs) commonly used in modern telephone systems demand exceptional care in this connection and it is highly desirable that, when once the teed connections have been made, they should not be subjected to more disturbance than is absolutely unavoidable.

The period during which the tees must be maintained is usually protracted, extending sometimes over several months, during which period it is almost impossible to avoid a certain amount of interference for purposes of—

(*a*) Testing in connection with the localization of faults;

time the tees are in existence, in order that desiccation by heat or other means may be constantly applied.

The flimsy paper insulation of the small-gauge cables mentioned will withstand little more than the careful handling which is essential for ordinary jointing purposes. With slight provocation the frail paper wrapping becomes unfolded and exposes the conductor, and if this should occur with many wires in a large cable, the result may be serious. The work entailed in clearing one such fault may cause similar faults.

In some measure the difficulty may be mitigated by treating the paper-insulated wires with hot beeswax and afterwards binding each wire with cotton thread in a direction reverse to the twist of the paper. This has the effect of minimizing the liability of the paper to untwist. The process may be laborious and expensive, but where a large number of tees have to be made the expense is fully justified.

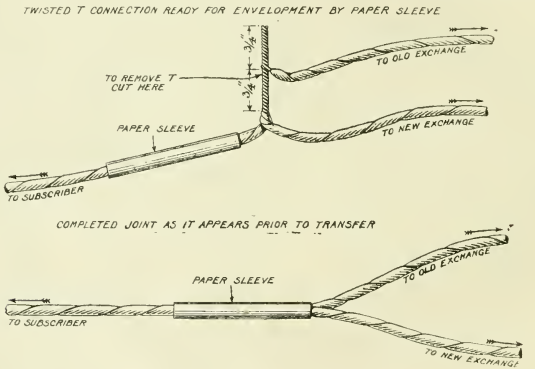


FIG. 10.—Method of making Tee Connections on Paper Insulated Conductors in Underground Cables.

(*b*) Introduction of additional teed connections necessitated by the provision of new services;

(*c*) Alteration to existing teed connections owing to removals, cessations, etc., of subscribers' services.

To some extent disturbance due to causes mentioned under (*b*) and (*c*) may be avoided by providing a certain number of spare pairs between each distributing point and both the old and the new exchanges when the teed connections are initially made, but this course may not be practicable owing to the limited number of spare circuits available.

Where large cables are concerned, the number of the insulated conductors may be so great as to preclude the whole being encased by plumbing work, and other steps must therefore be taken to maintain the exposed paper-core cables in a perfectly dry state, a matter of some difficulty and one which may involve the constant attendance of a skilled hand during the whole of the

Fig. 10 illustrates a suitable form of tee connection. The method permits the removal of the tee without disturbing the through connection and facilitates identification of the wire to be cut away.

Cast iron cable boxes have been utilized in an attempt to facilitate hermetical closure of the cable and to provide ready means of access to the tee connections. If such a measure be adopted, it is still desirable that the wires should be waxed and bound in order that they may satisfactorily withstand any handling to which they may be subjected. The box introduces limitations in the available space, and access to the wires is even more difficult than in the case of an open joint. No advantage is gained by their use except perhaps where the number of wires to be dealt with is limited.

Suitable methods of forming tee connections on open wire lines are illustrated in Figs. 11, 12, and 13.

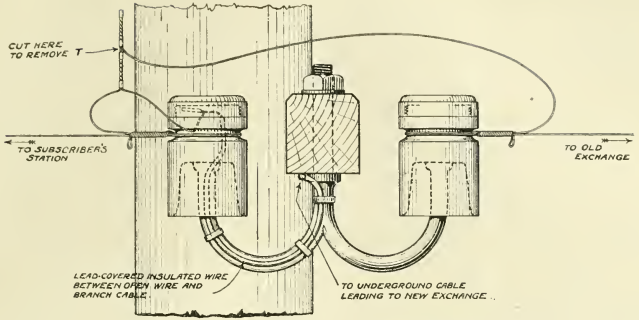

CUT HERE TO REMOVE T
TO SUBSCRIBER'S STATION
TO OLD EXCHANGE
LEAD-COVERED INSULATED WIRE BETWEEN OPEN WIRE AND BRANCH CABLE
TO UNDERGROUND CABLE LEADING TO NEW EXCHANGE

FIG. 11.—Method of forming Tee Connections on Open Wires: (*a*) At New Distributing Point on existing Open Line.

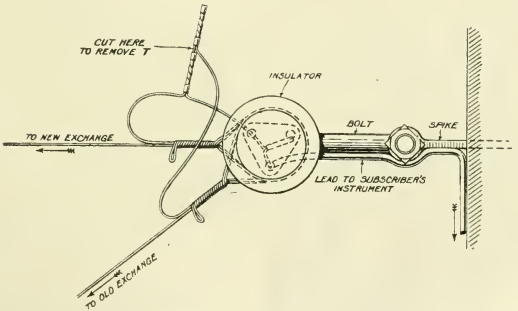


FIG. 12.—Method of forming Tee Connections on Open Wires: (*b*) At Subscriber's Station Leading-in Point.

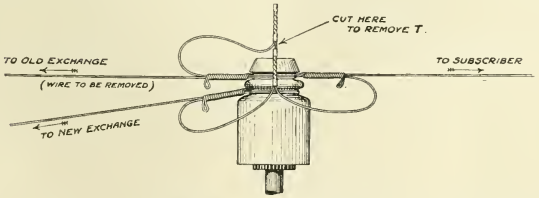


FIG. 13.—Method of making Tee Connections on Open Wires: (*c*) At point on existing Open-wire Line.

When the line arrangements for transfer admit of the tees being made within the new exchange the serious difficulties introduced by external teeing points are entirely removed. In the case illustrated in Fig. 6 the tee connections can conveniently be made at the main distributing frame of the new exchange and a suitable method of forming the individual tees is

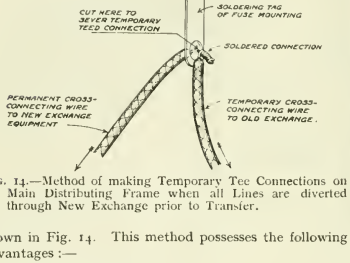

TO SUBSCRIBER'S LINE
SOLDERING TAG OF FUSE MOUNTING
CUT HERE TO SEVER TEMPORARY TEED CONNECTION
SOLDERED CONNECTION
PERMANENT CROSS-CONNECTING WIRE TO NEW EXCHANGE EQUIPMENT
TEMPORARY CROSS-CONNECTING WIRE TO OLD EXCHANGE.

FIG. 14.—Method of making Temporary Tee Connections on Main Distributing Frame when all Lines are diverted through New Exchange prior to Transfer.

shown in Fig. 14. This method possesses the following advantages:—

(*a*) It is economical;

(*b*) It admits of temporary disconnection of the tee piece for testing purposes without disturbance of the permanent portion of the new circuit;

(*c*) The tees can be cut away rapidly without disturbing the through connection, which is left in its permanent state, no further attention being required and no evidence of the tee remaining.

V. PREPARATORY WORK AT SUBSCRIBERS' STATIONS.

If the electrical operation of the new exchange be similar to that of the old exchange no modifications to the apparatus at the subscribers' stations will be necessary. If, however, a change in the system be involved, consideration must be given to the modifications to be made at the subscribers' end in order to conform to the different method of working.

For exchanges of 500 lines and upwards, the magneto-calling local-battery system has now given place to the more modern central-battery system, and it follows, therefore, that the removal of a telephone exchange is often accompanied by a change in the system of working from magneto to central battery by which the introduction of automatic calling and clearing effects a quicker service. The displacement of the magneto generator and primary batteries at the subscriber's station renders a complete change of apparatus desirable although not absolutely necessary.

The following three alternatives for treatment of subscribers' installations are presented:—

(*a*) Fix new central battery apparatus alongside the old and provide a change-over switch to be operated by the subscriber at the time of transfer for changing over to the new apparatus. This method is to be deprecated in consequence of increased cost, restricted accommodation for apparatus, and possible trouble by misoperation of the switch by the subscriber.

(*b*) Modify existing apparatus to permit of central battery working until the modern central battery apparatus is installed after the transfer.

It will usually be economical and convenient to adopt this alternative in cases of subscribers' simple sets and at stations with only one extension. Replacement of the old instruments by modern central battery apparatus may be carried out and full central battery conditions established as convenient after the transfer.

(*c*) Install new central battery apparatus prior to the date of transfer, introducing the modifications necessary to provide for satisfactory working until the transfer has been made.

This method is recommended for installations with switchboards where displacement of the old apparatus has been decided upon. It possesses the important advantage that the work to be done after the transfer is reduced to a minimum. The modifications required are inconsiderable, consisting only of the provision of ringing facilities and of battery power for speaking purposes. If power for the branch exchange is to be supplied by lines from the main exchange these power lines should, if practicable, be installed in time to avoid the use as a temporary expedient of primary cells.

The exact practice which it is best to follow to suit all circumstances cannot of course be laid down. Existing systems which may have to be considered vary in their circuit arrangements and in other details; local conditions and individual subscribers' requirements also influence the matter and, further, the demands to be met during the transitionary period of working vary with different localities and exchanges and the size of the undertaking. It is necessary, therefore, that each transfer should be dealt with according to its particular merits.

In order that the magneto apparatus comprising subscribers' installations may be made to conform to central battery working, attention should be given to the following points:—

(*a*) *Insertion of condensers.*—To maintain an open circuit when the receiver is hung upon the switch hook, condensers of 2 mfd. capacity are inserted at the following points:—

(1) Bell circuit of subscribers' single-instrument installations.
(2) Bell circuit of extension instruments.
(3) Bell circuit of extension switches.
(4) Circuits of extension bells joined direct across lines having connection to exchange.

Diagrams showing condensers fitted at the three first-mentioned points are given in Fig. 15.

It is undesirable to utilize at private branch exchanges the existing magneto apparatus, as considerable work will be entailed, but circumstances may arise which make this course unavoidable, in which case it may be necessary also to insert condensers in circuit with—

(5) Exchange line indicators.
(6) Extension line indicators which are not cut out of circuit when connection to the exchange is established.
(7) Ring-off or clearing indicators.
(8) Operator's speaking-set.

(*b*) *Insertion of holding coils.*—To guard against premature clearing signals being given at the exchange from private branch exchange installations not replaced by central battery apparatus prior to transfer, it may be necessary to provide "holding coils" which may be brought into circuit with the exchange line, when engaged, during the time the operating instrument is utilized in speaking to an extension station.

(*c*) *Polarity of receivers.*—It is necessary to ensure that the receivers of all instruments are connected in such a way that the current received over the line from the central battery will augment rather than reduce the magnetism of the receiver magnet. The test set shown diagrammatically in Fig. 16 will facilitate determination as to whether the receiver is correctly joined up. The electrical state of the line under central battery conditions is reproduced when the reversing key is in the normal position and the A and B lines

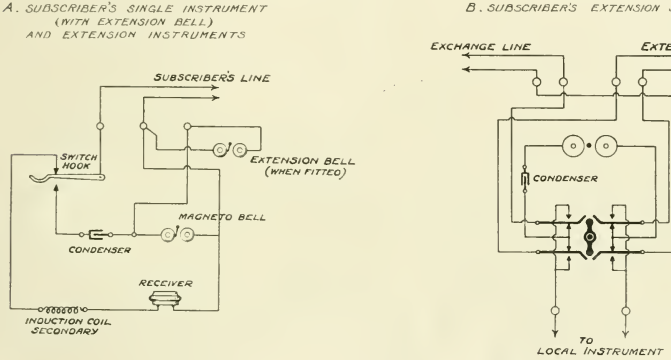


FIG. 15.—Modifications to Magneto Apparatus for Central Battery Working.

Diagram showing Condensers fitted in:—
(*A*) Bell circuit of telephone instrument. (*B*) Bell circuit of extension switch.

respectively joined up to the positive and negative poles of a 40-volt battery, through two 70-ohm retardation coils. The reversing key is manipulated by the test clerk whilst the instrument fitter co-operates by listening at the subscriber's end. The latter indicates in which position of the key reception is improved and the test clerk decides whether or not the receiver requires to be reversed.

(*d*) *Internal wiring.*—The internal wiring should be tested for insulation and examined throughout and any observed defect remedied. Alterations to wiring in cases where the leading-in point is being changed should also be provided for.

VI. Preparatory Work at Old Exchange.

In ordinary cases the work to be carried out at the existing exchange prior to transfer will be mainly that of testing out the circuits in conjunction with instrument fitters, and making line changes with line foremen and jointers. Where a large number of subscribers' lines is concerned, the amount of testing to be done will be considerable and it may be necessary to augment the existing testing equipment in order that the ordinary fault and maintenance testing may not be interfered with and that the special testing may be expedited.

Owing to the large amount of work to be done on working plant during the period when the preparatory work is in hand, the number of faults to be dealt with is likely to become inflated above the normal and their localization and clearance must be facilitated. The staff engaged in the maintenance of the existing exchange and the plant associated with it should therefore be kept well informed of the line work which is proceeding.

The changes to be made at subscribers' installations by the fitting staff may be controlled from the old exchange.

A form, reproduced in Fig. 17, is recommended for the record of preliminary tests and work done at subscribers' premises, and may be posted at the old exchange test-desk as the work progresses.

The preliminary insulation tests already referred to under "Preparatory Line Work" may be commenced before any work at subscribers' premises is put in hand, and the tabulated results will be an indication of the increase of insulation required. These tests may be made by connecting in parallel the *a* and *b* wires of the loop, and the internal wiring and the subscribers' apparatus will therefore be included. A suitable figure representing the minimum insulation permissible under these conditions may be fixed, and when the pre-determined minimum figure is not attained the particular case will require attention.

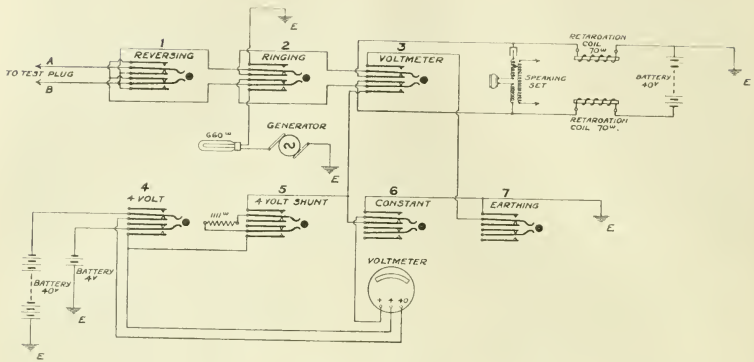

A
TO TEST PLUG
B
1
REVERSING
2
RINGING
3
VOLTMETER
RETARDATION COIL 20W
SPEAKING SET
BATTERY 40V
RETARDATION COIL 70W
E
GENERATOR
660~
4
4 VOLT
5
4 VOLT SHUNT
6
CONSTANT
7
EARTHING
VOLTMETER
BATTERY 40V
BATTERY 4V
MANIPULATION
DEPRESS KEYS NUMBERED
(1) TO CONNECT GENERATOR TO A LINE ..... 1 & 2
(2) " " " " " B " 2
(3) " " " " A & B LOOP 2
(4) TO TEST INSULATION A LINE, 40 VOLTS ..... 1 & 3
(5) " " " B " " " 3
DEPRESS KEYS NUMBERED
(6) TO TEST RESISTANCE TO EARTH, A LINE, 4 VOLTS ..... 1, 3 & 4
(7) " " " " " B " " ..... 3 & 4
(8) " " LOOP RESISTANCE, A & B, 4 VOLTS ..... 3, 4 & 7
(9) TO INTRODUCE SHUNT ON 4-VOLT SCALE 5
(10) TO READ VOLTMETER CONSTANT 6

FIG. 16.—Testing Circuit for testing out Lines from Magneto Exchange preparatory to conversion to Central Battery Working.

TRANSFER FROM ..... TO ..... EXCHANGE.

RECORD OF PRELIMINARY TESTS OF SUBSCRIBERS' LINES AND WORK DONE AT SUBSCRIBERS' PREMISES.

* Preliminary insulation test to be taken on *a* and *b* lines together. Minimum ohms .....

Subscribers' No.	* Preliminary Insulation Test in Ohms	Fitter's Initial Visit										Remarks
		Receiver Polarized	Condenser Fitted	Insulation Test: Line only *a*	Insulation Test: Line only *b*	Insulation Test: Line and Internal Wiring *a*	Insulation Test: Line and Internal Wiring *b*	Speaking	Date	Dockets: No.	Dockets: For	Dockets: No.	Dockets: For	

FIG. 17.

100,000 ohms is regarded as a safe figure for a central battery exchange working at 40 volts.

As the work at each subscriber's station is completed, tests from the exchange in conjunction with the fitter are made to ascertain—

(*a*) The insulation of the circuit.

(*b*) Whether condensers have been fitted at the requisite points.

(*c*) Whether the receivers are connected correctly.

(*d*) Whether the circuit is working satisfactorily.

VII. Preparatory Work at New Exchange.

When the installation of the new exchange equipment is sufficiently advanced, the work which has to be done there in preparation for the transfer may be taken in hand.

In bringing into use simultaneously the varied and numerous pieces of apparatus comprised in a modern telephone exchange of appreciable size, there is some risk of failure of certain units and it is necessary to ensure beforehand by exhaustive and methodical tests that every working part properly performs its functions under all conditions of service, and that, so far as is practicable, all possibility of partial or complete breakdown of any unit is eliminated.

It has been assumed that the new exchange plant proper has been installed in its entirety and that the only work to be done is that which is necessary in order to bring it into service.

The test clerks at the old and the new exchanges must work in close co-operation in connection with the joining up of the subscribers into the new exchange, and both should be fully acquainted with the progress of the work.

One or more direct telephone lines between the old and the new exchange test-desks will be required. The whole of the approved records of line and exchange plant and of the subscribers to be transferred should be in readiness by the time the work of diversion commences; entries may then be made in respect of each circuit as it is joined up.

When the main distributing frame is available, the necessary cross-connections may be commenced. These may be carried out from the information supplied by the cable-distribution schedules, complete copies by this time being in the hands of the test clerk. If the main frame cross-connecting is done in advance of the lines being put through by the jointer, considerable saving in labour will be secured and the work generally expedited.

As advice is received from the jointer of the circuits shunted into the exchange, the procedure recommended below in connection with each line may conveniently be followed by the test clerk—

(*a*) Verify that the main distributing frame cross-connection is already joined up to the correct exchange number.

(*b*) Remove heat coils from protector of respective line and insert fuses on main distributing frame.

(*c*) Test out line and confirm the subscriber's telephone number.

(*d*) From the cable distribution schedule check off circuit as "available at new exchange" and insert the necessary entries in all records concerned.

(*e*) Advise the test clerk at the old exchange of the tee connection having been made.

(*f*) Advise the jointer when each group of lines with which he is concerned has been dealt with.

TRANSFER FROM ..... TO ..... EXCHANGE

SWITCHBOARD DISTRIBUTION OF SUBSCRIBERS' LINES.

Numerical List.

Subscribers' No.	Panel No.	Jack No.	Register No.	Calling Lamp Cap	

FIG. 18.

Private lines, extension lines, and other lines which will merely pass through or via the main distributing frame should be diverted permanently and cut out of the old exchange. At the time of transfer only lines

TRANSFER FROM ..... TO ..... EXCHANGE.

SWITCHBOARD DISTRIBUTION OF SUBSCRIBERS' LINES.

Subscribers in Position Order.

Panel No.	Jack No.	Subscribers' No.	Register No.	Calling Lamp Cap	

FIG. 19.

actually operated at the old exchange will then be left to be transferred.

By the time the test-room equipment is ready, the test clerk should be in possession of lists showing the distribution of subscribers on the calling equipment of the new switchboard. Headings recommended for

these lists are given in Figs. 18 and 19 and the information contained therein will enable the work of cross-connecting on the intermediate distributing frame to be carried out before the instrument fitter makes a final visit to the subscriber's installation.

When the work of diversion is sufficiently advanced and the new central battery switchboard completed, instrument fitters should make a final visit to the subscribers' stations before the transfer. This visit is necessary in order to demonstrate practically that the working of each circuit is in all points satisfactory under central battery conditions. The following procedure is recommended :—

(*a*) The fitter reports to the test clerk at old exchange the number of subscriber from which he is speaking.

(*b*) The test clerk at old exchange informs test clerk at new exchange and disconnects line from old exchange by withdrawing heat coils on main frame.

the test clerk at the old exchange is instructed to restore the circuit. Fig. 20 shows the headings of a form recommended for recording the results of these tests.

VIII. Final Preparations.

It is desirable that the final arrangements should not be commenced earlier than is essential. Unless very cogent reasons demand otherwise, the transfer operation should not be deferred beyond the day fixed, and some little margin over and above the time estimated to be required for the final preparations should therefore be allowed in order to meet any unexpected delays which may possibly occur.

The work to be carried out is as follows :—

(1) *Final tests of subscribers' lines.*—These are made at the test desk of the new exchange and may occupy several days, depending upon the number of lines to be tested and the number of testing officers

TRANSFER FROM ..... TO ..... EXCHANGE.

Record of Final Tests of Subscribers' Circuits.

(To be maintained at New Exchange Test-desk.)

Subscribers' No.	Insulation			Ohmic Resistance of Looped Line	Receiver	Condenser	Transmission	Tests of Line to New Switchboard					Dockets			
	Line Wiring and Instrument	Line only						Calling	Speaking	Ringing	Supervisory	Subscribers' No.	No.	For	No.	For
		a	*b*													

Fig. 20.

(*c*) The test clerk at new exchange plugs into the reported line on main frame, speaks to fitter, and ascertains by testing whether :—

(1) Condenser is fitted.

(2) Transmission is satisfactory.

(3) Receiver is correctly connected

(4) Insulation and conductivity not lower than figures allowed.

Each extension line is similarly treated and any defect remedied if possible at the time, or otherwise docketed for later attention.

(*d*) The test clerk withdraws test plug, connects line through to new switchboard by inserting heat coils, and requests switchroom attendant to take the call.

(*e*) The circuit is then tested out between subscriber's station and switchboard under all normal working conditions.

(*f*) The switchroom attendant informs test clerk of result of test. The heat coils are then withdrawn and accommodated. Each circuit to be transferred is proved to ensure that—

(*a*) The insulation and conductivity of the line are satisfactory ;

(*b*) Each subscriber is connected to the correct exchange equipment ;

(*c*) The condenser is in circuit ;

(*d*) Speaking is satisfactory.

(2) *Final test of junction circuits.*—Each junction circuit to be transferred requires to be finally tested under actual working conditions between the new exchange and the distant exchange. If the line is to be transferred at the distant end to new equipment for working to the new exchange, arrangements will have to be made for attention there. Order-wire junctions should be tested through the cords at the incoming end by extending the circuit to the monitor's table or other convenient exchange line and the supervisory signals and the speaking proved.

All junction circuits duplicated for the transfer should be similarly tested and left in working condition.

Order wires also require to be tested.

(3) *Relay tests.*—Although the line and cut-off relays have previously been tested out and adjusted, they may have been subjected to such frequent handling that a final examination and test of each relay is advisable.

(4) *Line fuse examination.*—Each fuse on the main distributing frame, also the contact springs (if any), should be examined. A continuity test in situ of all fuses, together with supporting spring contacts, should be made to ensure that all fuses are making satisfactory contact and are not disconnected.

(5) *Heat coil test.*—Tests for disconnection and short-circuit should be made.

(6) *Lightning arrester test.*—Carbon arresters should be removed from the frame, dusted and replaced, care being taken to ensure that the mica separators are in position They may afterwards be tested to prove

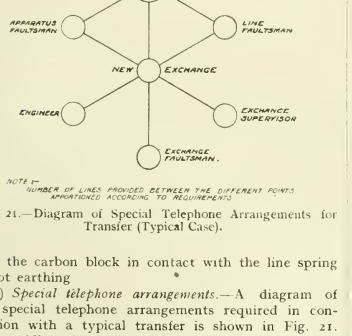


FIG. 21.—Diagram of Special Telephone Arrangements for Transfer (Typical Case).

that the carbon block in contact with the line spring is not earthing

(7) *Special telephone arrangements.*—A diagram of the special telephone arrangements required in connection with a typical transfer is shown in Fig. 21. In providing these circuits, steps should be taken to ensure that risk of failure at the critical moment is reduced to a minimum.

(8) *Meter readings.*—The readings of subscribers' meters must be recorded immediately prior to the transfer.

(9) After withdrawal of the fibre separators from the cut-off relays at the transfer, it is advisable to verify that the relay springs are making contact. The following test for this purpose should be applied. A headgear receiver and a 2-microfarad condenser are connected in series, the free terminal of the condenser being connected to earth. A wire attached to the free terminal of the receiver is first tapped upon the lower spring of the cut-off relay, then against the upper. This should alternately charge and discharge the condenser and a click should be heard in the receiver. The absence of a click denotes a fault. The requisite number of sets for this test should be arranged not later than the day prior to transfer.

(10) On or before the evening of the day prior to the transfer, attention should be given to the following details :—

(*a*) Provision of tapes as previously described for removal of heat coils on main frame at old exchange.

(*b*) Insertion of separators between the spring contacts of cut-off relays.

(*c*) Insertion of all heat coils in working positions on the main distributing frame. This operation should follow (*b*) and on no account be attempted before.

Reference to Fig. 2 will show that when the heat coils have been inserted, the subscriber's line is connected to the local and multiple jacks of the new switchboard and that the fibre separators constitute the only separation between the subscriber's line and the line relay and central battery. It is therefore essential that the cut-off relays and the multiple and local jacks should not be subjected to interference.

Fibre separators must not be inserted in relays associated with any lines already working on the new exchange.

(11) The special instruction circuit between the test desks of the old and new exchanges, and also any other lines which must remain working through or into the old exchange after the transfer, should not be included in the circuits to be disconnected by the extraction of heat coils. This may be arranged by passing the tapes in front of, instead of behind, the heat coils associated with such lines. If the number of lines concerned be small, it may be better to remove them entirely from the main frame and by this means secure immunity from possible trouble.

(12) *Provision for "glow" tests.*—Each operator concerned will require a resistance plug for use in carrying out the "glow" tests. A plug with self-contained resistance of 750 ohms is suitable. Insertion of the plug into the answering jack of a subscriber's line connects the resistance of the plug in series with the central battery and the line relay, actuating the latter and causing the calling lamp to glow.

(13) *Rehearsal.*—On the evening of the day prior to that fixed for the transfer, rehearsal of the operation should be carried out under the direction of the officer responsible. Each man who is to take part should be interviewed at the position allotted to him by the officer controlling the transfer, in order to make certain that the duties are thoroughly understood.

IX. The Transfer Operation.

We now arrive at the critical operation, the success of which will largely depend upon the thoroughness with which the whole of the preliminary work has been arranged and carried out.

During the period immediately prior to the transfer, the circuits already connected in working condition to the new exchange should be tested out and proved in order. The service lines already working on the exchange and the junction lines from other exchanges

already connected up for service in advance of the transfer are amongst the circuits referred to.

At the pre-arranged time, the first portion of the junction circuits to be transferred, viz. those which have been scheduled for treatment in advance of the subscribers' lines and which may approximate to about half the total number of junction circuits to be dealt with, should be diverted. This is accomplished by first inserting insulating plugs in the junction test-jacks of the circuits concerned at the old exchange and immediately afterwards withdrawing the plugs from the corresponding jacks at the new exchange. These circuits may then be tested out as explained under "Traffic and Operating Considerations," and any faults cleared before proceeding with the remainder of the lines.

At a fixed time shortly before the transfer, all faults outstanding should be advised by the test clerk at the old exchange to the test clerk at the new exchange. These are thereupon docketed for attention and the circuits plugged out on the main frame.

At the appointed time the subscribers' lines and the remainder of the junction lines should be dealt with as rapidly as possible in the following manner:—

(*a*) The test clerk at new exchange requests over special telephone line the removal of heat coils at old exchange and waits for advice that this has been accomplished.

(*b*) On receipt of this intimation, the test clerk gives pre-arranged signal to:—

(1) Extract separators from cut-off relays, and

(2) Withdraw remainder of plugs in junction test-jacks.

(*c*) The exchange supervisor and the test clerk at old exchange are then advised that the transfer has been accomplished, and the officer deputed to carry out relay tests is directed to proceed.

(*d*) The test clerk at old exchange informs supervisor there that transfer is completed.

Should it be necessary to cut away any tees simultaneously with the removal of the heat coils at the old exchange, in order to sever from the respective circuits any sections of line of doubtful insulation, instructions should be passed over the special telephone lines provided (see Fig. 21) to men stationed at the teeing points concerned; this should be done immediately before the test clerk at the old exchange is instructed to withdraw the heat coils.

A description of the testing-out process by the operating staff at the new switchboard after transfer is given under the section headed "Traffic and Operating Considerations."

As the fault dockets are received at the test desk, the respective circuits are put under test and the proved faults passed forward over the special telephone lines provided for that purpose (see Fig. 21) to (*a*) exchange faultsman, (*b*) line faultsman, or (*c*) subscribers' apparatus faultsman, to be dealt with in standard manner.

X. Traffic and Operating Considerations.

Choice of day and time for transfer.—Traffic conditions must be taken into account in selecting a day and time for the transfer operation. For several reasons it is desirable that a time should be chosen when the volume of traffic to be handled will be at a minimum, and that the same condition should obtain for as long a period as possible immediately following the transfer operation. This will ease the operating staff, give them opportunity for the requisite testing, minimize interruptions to the service, and permit of a large proportion of the junction circuits being transferred in advance of the subscribers' lines; also opportunity will be afforded to remedy any defects which may arise and to carry out any work, such as the removal of tee connections, which requires to be done before busy traffic conditions are resumed.

The choice of the least busy period is particularly helpful in the transfer of junction lines. The provision of these lines being based upon the traffic requirements of the busy hour, it follows that at the slack period a large proportion of them will be idle. This renders it possible to transfer in two independent groups, the first some time before and the remainder simultaneously with the subscribers' lines. Time is then available for the first group of lines to be tested out in readiness for service at the general transfer. Sufficient junctions are of course left connected to the old exchange to carry the traffic satisfactorily during the interim.

Switchboard distribution of subscribers' lines.—In order to secure uniformity of attention to calls, it is necessary to distribute subscribers' circuits over the answering positions of the switchboard not in numerical order, but in relation to their traffic activities. Such distribution must of course be based upon actual observation of conditions obtaining for each subscriber's line. The work entailed may be of an extensive character according to the number of lines concerned. It must be undertaken many weeks before the transfer is due, so that a scheme for the grouping of the subscribers' circuits may be completed and copies of the distribution schedules may be in the hands of the new exchange test clerk by the time the intermediate frame is in readiness for cross-connecting. If required, new telephone numbers may be allotted at the time these schedules are prepared. Suitable forms for showing the subscriber's switchboard distribution are illustrated in Figs. 18 and 19.

Programme.—A programme of instruction for the guidance of the operating staff concerned in the transfer should be drawn up in order that no essential detail be overlooked.

Training of operators.—Operators who are to be transferred from the existing to the new exchange should be familiarized with the working and local conditions of the new board in advance of the transfer. If a change in the operating procedure be involved, the telephonists should undergo a systematic course of training in order that they may become proficient in manipulation of the new switching equipment. In the case of large transfers, a rehearsal of the transfer operation in so far as the operating staff is concerned may advisedly be made a few days prior to the transfer date.

Operating procedure.—The operating arrangements to be made in connection with a transfer will of course

vary with different conditions, but the procedure outlined below may be regarded as typical.

(*a*) At all exchanges concerned, not later than the time selected for transfer of the advance group of junctions, the incoming order-wire junctions to be transferred in advance of the subscribers' lines are

TRANSFER FROM ..... TO .....
EXCHANGE.

OPERATOR'S SPEAKING TEST OF JUNCTION CIRCUITS.

Exchange..... Operator.....

Exchange	Junction No.	Result of Test	Time	Fault Cleared	
				Nature	Time

FIG. 22.

thrown out of use. These junctions must be cleared of traffic by the pre-arranged time. The selected outgoing signal junctions are plugged up on spare positions so that they may test "engaged." From this time up to the time of transfer, only junctions which have not been thrown out of use are selected for service by B operators attending order-wire positions. When the transfer has taken place, until completion of the junction tests, B operators allot junctions only from those which have been previously transferred and which by that time should be ready for service.

(*b*) A sufficient number of A operators should be deputed to be in their places at the new exchange at the pre-arranged time to carry out the tests of the outgoing junctions transferred in advance. Each of these operators is provided with a form (see Fig. 22) upon which are entered particulars of the whole of the junctions to be tested by her. Each operator commences the tests upon receipt of the signal to do so, and proceeds according to a definite programme which shows the time when the distant exchange is expected to co-operate in the test. The junctions are spoken over to the monitor's desk, or a specially provided service telephone, so that the junction cords are included in the test, and signalling also is proved, any faults being recorded on the form provided at each exchange. Junctions previously provided are included in the test.

(*c*) The tests of incoming junctions at the new exchange may be conveniently originated by A operators at the distant exchanges concerned, the procedure being similar to that described under (*b*).

(*d*) When the tests of the advance junctions have been made, faulty cases may be passed forward for attention.

(*e*) For a short period (say five minutes) before and after the time fixed for transfer, callers on all other exchanges asking for subscribers connected to the exchange to be transferred are informed that an alteration is being made and are requested to renew their application later.

(*f*) During a period of, say, five minutes prior to the transfer, all calls in progress to or at the existing exchange are challenged and the subscriber is asked to terminate the conversation quickly as otherwise he will necessarily be disconnected shortly.

(*g*) Immediately advice is received at the old exchange that the transfer has been made, the operators may proceed to the positions allotted to them at the new exchange.

(*h*) Immediately the signal is given at the new exchange that the transfer is accomplished, the junction-testing operators commence the test in accordance with a pre-arranged programme, of the junctions which have been transferred together with the subscribers' lines, the procedure followed being similar to that described under (*b*).

(*j*) In accordance with the pre-arranged time-table

FORM FOR RECORDING RESULTS OF OPERATORS' TESTS OF SUBSCRIBERS' CIRCUITS.

Slip No.										Panel No. ....
Subscribers' No.										
Glow										
Ringing and speaking										

Note.—O.K. tests distinguished by √. Faults distinguished by X.

FIG. 23.

showing the testing time of each junction concerned, "A" operators at distant exchanges responsible for testing the outgoing junctions to the new exchange proceed with the tests of those junctions transferred together with the subscribers' lines, the procedure being similar to that previously followed.

(*h*) A sufficient number of A operators are provided at the new exchange to operate the ordinary traffic of the exchange and to carry out the "glow" and speaking tests of the transferred subscribers' circuits. Each operator is provided with a number of forms or slips (see Fig. 23) on which are already entered the numbers of the subscribers' lines allotted to her for test, and immediately the signal is given the tests are commenced. The "glow" test is made by inserting the resistance plug specially provided for the purpose into each local jack successively, and if the calling lamp fails to glow an entry is made upon the form accordingly. After this test has been applied the ringing and speaking tests are forthwith commenced, the operator observing the following procedure :—

(*a*) Calling plug inserted into multiple jack of selected subscriber and ringing key depressed.

(*b*) Answering subscriber informed that line is being tested and requested to wait.

(*c*) Calling plug withdrawn from multiple.

(*d*) Glow on answering position verified.

(*e*) Calling plug inserted into local jack and subscriber informed that calling signal is in order.

Circuits of special importance, such as hospitals, fire stations, etc., are distinctively shown on the testing forms for prior treatment.

Faults detected by operators or reported by subscribers are entered in the appropriate column of the form, the numbers of subscribers whose circuits prove to be in order being also distinguished.

As the tests are completed the operators' slips are passed to the telephonist at the exchange testing position, who, after carrying out the necessary tests, prepares a fault docket in respect of each faulty circuit. Periodically these dockets are collected and forwarded to the test clerk for further attention, and are returned to the testing operator on completion so that the forms held at the testing operator's position may be completed.

A time of light load on the exchange being chosen for the transfer, it will no doubt be the case that many business firms will be closed. In order to reduce ineffective calling on subscribers' lines which are in proper working order, but unattended at the subscribers' ends, it is usual to advise the subscribers of the impending transfer and to request them to say whether their telephone will be attended at that time. All cases where the reply is in the negative are distinguished upon the operator's testing forms and, unless the glow test is unsatisfactory, they are not reported as faults until efforts which are made to obtain reply on the next working day prove unsuccessful.

The adoption of a method similar to that described of recording the results of tests made by operators, provides information which may ultimately be useful in connection with inquiries regarding specific faults, and enables subsequent judgment to be formed of the relative degree of success which has attended the transfer.

XI. Post-transfer Work.

After the transfer has been accomplished, and if the exchange is working smoothly, attention may be directed to the operation of restoring the affected working plant.

Removal of tees.—The cutting away of tees should not be commenced until the exchange staff has finished the tests of the whole of the transferred lines. Assuming that the exchange as a whole is then working satisfactorily, instructions may be given to cut away all tees terminating on the springs of the protectors at the old main frame. The early removal of all tees is advocated, as a possible source of faults will thereby be removed. In cutting away tees in underground cables, each wire of a pair should be cut separately to avoid the momentary glow of the calling lamp which would otherwise be occasioned. When all the tees at one point have been removed, the final jointing operations may be proceeded with, and when completed the joints should be plumbed in the ordinary way.

The prompt severance of all tees on open wire lines should be immediately followed by the removal of the discarded portion of the circuit and the final restoration of the open line plant where necessary.

Final cable operations.—Although the arrangements may have been such as to reduce to a minimum the work to be done after the transfer, there must generally remain some work which cannot be completed until those wires which have been temporarily employed to effect the transfer have been liberated. This work will usually consist of—

(*a*) Reinstatement of spare wires which were utilized for transfer by temporary diversion ;

(*b*) Redistribution of pairs in cables affected by transfer ;

(*c*) Recovery of discarded cables ;

(*d*) Final insulation and air-pressure tests of all newly installed and disturbed existing cables, followed by desiccation if necessary.

Disposal of transfer impedimenta.—All apparatus, appliances, etc., remaining as the aftermath of the transfer should be recovered.

Dismantling old exchange.—The old exchange equipment may be dismantled and disposed of as required, care being taken not to interfere with the main frame until any remaining working circuits have been permanently diverted and the tees cut away.

Change of apparatus at subscribers' installations.—The replacement of existing by modern central battery apparatus not carried out at subscribers' premises prior to the transfer may now be proceeded with systematically, and the necessary adjustments made where necessary to central battery apparatus previously fixed.

XII. Organization.

To secure the most economical and efficient results in connection with a transfer of material dimensions, careful organization of the whole of the work involved is obviously necessary. This is true not only in regard to the final preparations and the transfer operation proper, but also, and perhaps even more particularly,

the preparatory work which is generally considerable and may occupy a period of many months.

From the point of view of economy, it is particularly essential that the various sections of work should be co-ordinated in such a manner as will preclude delay being caused to any section of the work by non-completion of any other section within the requisite time.

It is of course not possible to stipulate here the sequence of operations, because each case will vary in its requirements, but broadly considered, the table given in Fig. 24 exemplifies the order in which the most important operations may best be conducted. Those works which may proceed simultaneously are distinguished and a space is provided for insertion of pre-determined dates by which completion is necessary. A programme prepared on these lines will constitute a guide to the responsible engineer and an aid in expediting the work.

In order to reduce to a minimum the liability of interruption to which the service will necessarily be subjected, it is preferable that the various works associated with a transfer should be organized in such a way that no work which can possibly be done before the actual transfer be left until afterwards. Work such as changing wires from one position to another on open lines, re-arrangement of wires in underground cables, making permanent any wires left in a temporary state, etc., is referred to, and reasons for the adoption of this precaution are as follows:—

(*a*) There is a greater possibility of disturbance in carrying out work on the central battery than with the magneto system.

(*b*) Workmen inexperienced in central battery working, although accustomed to the magneto system, may not at first appreciate the greater care required.

(*c*) Operators transferred from a magneto to a central battery switchboard do not at once obtain full proficiency and should be caused as little trouble as possible from interference with working circuits.

All operations unconnected with the transfer such as new subscribers' services, removals, and other work of a similar character should be entirely suspended if such a course be possible. Once the work of shunting the lines into the new exchange has begun and the old cable system has been disturbed, connection of new lines introduces a disturbing element, creating delays, additional expense, and increased risk of faults and errors. It is recognized, however, that certain alterations and additions are inevitable, but they should be reduced as far as possible.

An essential to successful transfer is the preparation of a complete programme embracing the whole of the work involved in the final preparations and in the actual transfer operation. This will guard against any

TRANSFER FROM ..... TO ..... EXCHANGE.

SCHEME OF OPERATIONS AND WORKS TIME TABLE.

Date for	1	2	3	4	5	6	7	8
Commencement	.....	.....	.....	.....	.....	.....	.....	.....
Completion	.....	.....	.....	.....	.....	.....	.....	.....
Order	1	2	3	4	5	6	7	8
Sections of work to be carried out	Provision of new exchange building	Installation of new exchange plant		Preparatory work at new exchange	Final preparations for transfer	Transfer operation	Changing subscribers' apparatus	
	Installation of new ducts	Installation of new cables and preparation of cable distribution lists	Testing and labelling cable circuits at teeing points	Teeing lines into new exchange			Cutting away tees, adjustments to underground plant	
	Alterations to subscribers' apparatus and wiring			Training of operators			Adjustments to open-line plant	
	Erection of new open-line plant, renewals, and alterations		Preparation of subscribers' switchboard distribution lists					

FIG. 24.

essential operation or requirement being overlooked. The following are headings recommended under which a programme may be prepared :—

(*a*) General scheme of transfer.

(*b*) Particulars of special telephone arrangements.

(*c*) Schedule of junction-line transfer arrangements.

(*d*) Numerical list of subscribers for entry of final test results.

(*e*) Testing arrangements for operating staff.

(*f*) Special arrangements for dealing with faults :— (1) line ; (2) subscribers' apparatus ; (3) exchange.

(*g*) Staff arrangements, including names, duties, and times of attendance of each member of staff taking part.

(*h*) List of service and other lines from which fibre separators must be omitted from cut-off relays.

(*j*) List of permanently provided junction lines.

(*k*) Detailed instructions for each officer engaged in the work of transfer, including those deputed to assist in the transfer of junction circuits at distant exchanges.

(*l*) Separate list for each teeing point of lines from which tees are to be cut away simultaneously with removal of heat coils.

(*m*) List of subscribers whose premises will be closed at the time of transfer.

(*n*) List of lines remaining through old exchange after transfer.

The positions to be manned for the transfer operation will be generally as follows :—

(*a*) Old exchange test-desk.

(*b*) Old exchange main frame.

(*c*) New exchange test-desk.

(*d*) New exchange main frame.

(*e*) Relay racks.

(*f*) Each exchange connected direct by junction lines to the exchange to be transferred (unless the lines concerned have been duplicated).

(*g*) New exchange faultsman.

(*h*) New exchange testing operator's position.

(*j*) Line fault control.

(*k*) Subscribers' apparatus fault control.

(*l*) Underground teeing points not closed in.

(*m*) Construction staff for removal of tees, if required.

It is advisable that complete control of the transfer operation should be vested in one individual situated at one recognized point of vantage. The most suitable position will no doubt be at or in close proximity to the test clerk's desk.

In conclusion, the author desires to express his indebtedness and thanks, first to Mr. Elliott, Superintending Engineer for the Northern District of the Post Office Engineering Department, for his kind encouragement and assistance in connection with the paper ; to Mr. Edmonds, Superintendent of Traffic for the London Telephone Service, for kindly reading through the draft paper and for his valuable suggestions ; to Mr. Bruce for his assistance in the preparation of drawings, and to various others who have, consciously or unconsciously, assisted in the preparation of the paper.

Discussion before The Institution, 24 January, 1918.

Mr. A. J. Stubbs : I am glad that the author dismisses the idea of transferring by groups of lines independently, as compared with transferring the whole at one operation. Even if there be two exchanges to be transferred and combined into one, it is still good practice that both be transferred simultaneously. His method of transferring existing line plant by teeing direct from cables, etc., is undoubtedly sound practice wherever it can be applied. The teeing of lines at the old exchange does not seem to present any appreciable advantage over arranging for the transfer by excluding that exchange. Also, transferring via the new exchange would be likely to be almost invariably somewhat expensive, because the incoming cables and the main distribution frame at the new exchange would have to provide for double the number of lines to be transferred. Although the author does not seem to favour the scheme that he describes when the plant between exchanges is limited, it appeals to me as being good engineering and distinctly economical—a method well worth maintaining as recognized procedure. Dealing with the preparatory work at subscribers' stations, his practice of completing the change at the private branch exchanges in advance is undoubtedly good. As regards the transfer of ordinary subscribers, the only comment that I would make is that we are now having to face a qualifying condition, when transferring to an automatic exchange, where it is impossible to leave the old instrument by itself as we must give the calling device of the automatic system. In that case, however, we economize by making the condenser of the new set serve for the purposes of the transfer while the old instrument is still in use.

Mr. A. Moir : A paper such as this emphasizes the great difference between the practices of the two sides of electrical engineering, i.e. power supply and telegraph and telephone engineering. It is this great difference which accounts for the very large amount of detail which the author has had to introduce into the paper. In the smaller details of so vast an operation it will always be possible for differences of opinion to exist, and I might illustrate that by saying that I slightly disagree with the author's remarks on page 394 of the paper. He disconnects the contact stops in the cut-off relays by inserting a fibre separator, which is removed after the transfer has been carried out. I prefer to insert a small wooden peg under the spring of the relay, which is similarly pulled out when the transfer is carried out but which has the advantage that it does not interfere in any way with the contact points of the relay, so that there is no possibility of leaving, as sometimes happens, a small portion of fibre on these important contacts. I would just add a few words of advice to those who may be placed in charge of a big transfer. First, on no account allow the fittings for the new exchange to be delivered in the new building until the bricklayers and plasterers have finished and the walls are perfectly dry. Nothing lowers the insulation of the multiple so rapidly as damp walls, and nothing is so

destructive of the highly polished fittings or the delicate contacts in relays as bricklayer's dust. The other point which I would suggest is this: never allow oneself to be rushed in carrying out a telephone transfer. A provisional date may be fixed if necessary, but let it be distinctly understood that it is a provisional date, and reserve the right to take another week, a fortnight, or three weeks, if one is not absolutely ready. In conclusion I will mention a point of general interest showing that the Post Office is not afraid of transfers. Between the date of the transfer of the National Telephone Company's undertaking and the outbreak of war I think nine new telephone exchanges were opened in London, providing additional subscribers' space for 62,000 new subscribers; and as many as 19 cases were under investigation for further new exchanges when the war broke out. Of course, all that work has since been stopped.

Mr. E. S. Byng: The various causes which necessitate a telephone exchange transfer, or "cut-over" as it is termed in America, may not be apparent to members who specialize solely on the heavier side of electrical engineering, and it may not therefore be realized how frequently this class of work has to be tackled by telephone engineers. Such transfers may be due to one of the following main causes:—lack of capacity, obsolesence, incorrect location, termination or completion of tenure, and fire. There is probably a greater necessity for the transfer or removal of telephone circuits than any other form of public service, and consequently it is somewhat surprising that, notwithstanding the frequency with which such transfers have to be arranged, so little information has been available on this subject in the past. There are one or two practical points to which I will briefly refer in regard to teeing-on. The difficulties and risks imposed by having external teeing points, especially in the present-day cables which may contain 800 or 1,000 circuits in one cable, cannot be over-emphasized. When 1,200-pair cables are in use in this country the difficulties will be even greater. On page 391 the policy of diverting the lines via the new exchange is advocated, and although there may be some objection to this proposition on account of the capital expenditure in providing the additional pipe and cable capacity, I believe there is much to commend it. The annual costs of cable plant are extremely small, whereas the cost of teeing points and all the circuit arrangements which are necessary if the line plant is limited, may be considerable, and from one's own experience subsidiary costs are invariably underestimated on account of the time expended in the clearance of faults. A further disadvantage is one which cannot be calculated in £ s. d., namely, the interruption to the service. More trouble has been caused through this than any other, and the question is therefore of vital importance. There is a considerable difference between working out a scheme for the temporary re-arrangement of the circuits on paper and the practical carrying out of the work. If capacity is limited it may be necessary to interconnect six or even more large cables in a manhole, and if a watchman is not provided continually it will be necessary to make a large plumbed joint embracing these various cables, which, when completed, resembles an octopus in shape. Should there be a flaw in the plumbing and the manhole be flooded, the whole telephone system may be broken down in consequence. An exchange transfer is a work of great magnitude, and probably represents the most worrying and complicated work a telephone engineer has to face. Experience has shown that the provision of more circuit capacity greatly facilitates the transfer of lines from one exchange to another, and incidentally relieves the engineer of a considerable amount of worry and anxiety. In other words, a transfer may be made in a complicated manner incurring heavy expense and certain risks, both of which, however, may be avoided by the judicious expenditure of a little more capital. The actual transfer and all attendant work is strictly a revenue charge; consequently, if capital be starved it may be at the expense of prodigious revenue costs. A further advantage of diverting circuits via the new exchange wherever possible prior to transfer, is that the connection of new lines is facilitated and they need not be disturbed again at a later date. The method of making tees as shown in Figs. 10 to 14 is a very great improvement on the old method where the three wires were made in the same twist. Not only was there the danger of cutting away the wrong wire, but the joint either had to be re-made or the third wire left in the twist. This has been successfully overcome by the author by having the teed wire as a continuation of the straight-through joint. The suggested forms for recording the number of faults which occur after the transfer, as illustrated in Figs. 22 and 23, are of very great service to the engineer, and indicate at once the extent to which the transfer has been satisfactorily carried out. Notwithstanding all the testing and re-testing during the course of the work, it is remarkable how faults come to light after the lines are diverted to the new exchange. Provided reasonable and proper care has been taken on the lines laid down, it should, however, be possible to carry out a complete transfer with less than 1 per cent of faults. An exchange transfer is usually arranged for a Saturday afternoon, when business houses are fairly quiet. This then enables any faults to be cleared during the week-end. The necessity for careful observation of the whole of the working plant until the post-transfer work has been completed and things have settled down, is not mentioned in the paper. This is rather an important point, for if the outside workmen do not exercise every possible care a large number of faults may develop, which will certainly lower the prestige of the operating company in the eyes of the public. The subscriber, having been advised by the traffic engineers that his line will be disconnected on a certain date in order to make the transfer to a new exchange, is perhaps more inclined to be lenient before the event than afterwards, as he cannot appreciate all the post-transfer work which has to be carried out and which may possibly interrupt his service occasionally.

Mr. G. H. Bryant: The paper has been of great interest to me, because from 1905 to 1910 I was engaged on the transfer from magneto to central battery

working of a number of the National Telephone Company's metropolitan exchanges. In general, the author has described the organization and methods that were employed to effect a transfer with a minimum of interruption to the service. There are, however, one or two points I should like to criticize in Section III of the paper. The method of effecting the transfer by previously inserting vulcanized fibre separators between the contacts of the cut-off relays which are pulled out at the time of transfer is, I consider, inferior to that employed at the majority of the exchanges transferred from magneto to central battery working in the metropolitan area. In this connection I will briefly outline the methods that were employed. In 1905 and 1906 it was the practice to insert microscopic cover glasses between the contacts of the cut-off relays prior to the transfer, and then to connect the subscribers' circuits of the new and old exchanges in parallel until the transfer took place, when the old exchange was cut out and operators stationed at the new switchboard momentarily plugged in all the subscribers' lines so as to operate the cut-off relays fully and enable the glasses to fall out. This method was abandoned because it was found that a number of the glasses did not fall out, while others broke into fragments which lodged between the contacts and caused faults. In 1907, experiments were made with pieces of vulcanized fibre in the manner described by the author, when it was found that on withdrawing these a number of the contacts were insulated by small particles torn from the surface of the fibre by the scraping action of the contacts. As might be expected, similar results were obtained with cardboard and paper. It was therefore decided to separate the contacts by holding the armature in the operated position. This was done by means of a match placed between the coil and armature (see Fig. 3 for the type of relay). Ten matches for a strip of relays were strung together on a stout thread, with ends for withdrawing. This method was used at Paddington exchange in 1907. As, however, the matches were found to be brittle, they were replaced by small, hard wood wedges about $\frac{3}{4}$ inch long by 3/16 inch wide. This method was employed at Gerrard exchange and the various other transfers in the metropolitan area from 1907 to 1910. The author states on page 394 that " where the protectors are provided with additional springs in order to admit of the insertion of the test plug without first removing the heat coils, the new and old equipments can be separated by wooden plugs at the protectors." This method has a disadvantage, inasmuch that the multiple of the new exchange is not connected to the subscribers' lines prior to the time of transfer. It was the practice in the metropolitan area to connect the new and old exchanges in parallel where possible for at least a week before the time of transfer, and to make a final test on all subscribers' lines from the new exchange multiple. The third conductors of the test plugs were temporarily disconnected so that the cut-off relays should not be disturbed. In regard to junction circuits, the author shows these in Fig. 8 as insulated at break jacks on the main distributing frame of the new exchange. At the transfers previously referred to, the bulk of the junction lines were connected to both new and old exchanges for some days prior to the time of transfer, because the circuits on the new switchboard did not interfere with the working of the old exchange. By this means the final testing was facilitated and a satisfactory transfer ensured. In the case of Gerrard exchange about 2,000 junctions were involved.

Mr. E. A. Laidlaw: I agree with Mr. Moir and also with Mr. Bryant regarding the cut-off relays and the insertion of fibre between the contacts. We made many experiments using fibre, glass, and other material, and although these did not cause very considerable trouble, it came out like this—that for about six weeks after the exchange was open we got more or less faults on the exchange. That is, every line was tested when the exchange was open and cleared, and the faults due to disconnections on the cut-off relays were in the neighbourhood of 5 to 10 per cent. It did not, however, end there, as for about six weeks faults on cut-off relays were more than normal. I, therefore, think that the practice of putting any material between contacts is bad, and that it is better to operate them by some mechanical means, wooden plugs or any method other than inserting material between contacts. The method shown in Fig. 7 for transferring line plant between new and old exchanges is, I think, especially good, but it is expensive. The cables, however, even after the transfer by this method, have eventually to be put permanently through, and I consider a study should be made in every case to see what cables could not be put through direct at the opening, and so save this expenditure. At large centres such as Manchester and Glasgow I found certain cases where a great number of subscribers close down their premises from Saturday noon to Monday, and in one case I remember in Manchester, we were able to join through a 300-pair cable direct, and only had to make temporary provision for eight subscribers whose businesses were not closed. In Fig. 8 the author states that all junction circuits are brought through jacks. Is this correct? My recollection is that the arrangement is only used for long open lines and for order wires, not for all junctions.

Mr. J. F. Edmonds: A very large amount of the work referred to by the author will have to be carried out as soon as normal conditions are resumed, and the paper will then be of even greater value to telephone men than now. The author has apologized because his paper is not so detailed as it should be. On the other hand, members who are not telephone engineers will probably not agree with him here. In my experience, however, when these transfers have to be carried out very many more matters have to be attended to than are covered in the paper. We on the telephone side in London have all had experience—luckily in the distant past—of the serious and widespread effect on the telephone service of a big city as a whole caused by transfers which have been carried out without due regard to the considerations set forth by the author. In London we have, say, 125,000 separate subscribers' circuits spread over the 640 square miles of the London Telephone Area, and I have known cases where changes have been carried out involving 5,000 or 6,000 lines, or only 4 or 5 per cent of the whole, but which have

adversely affected the service over the whole area. It might be thought that the effect would be restricted to the circuits directly concerned, but this is far from the case, and it has taken months of hard work to get back the service to a high standard, and longer still to regain the good opinion of the public. It is worth very considerable expenditure to avoid such dislocation of the service. On the other hand, where methods have been employed as described by the author, the recent transfers in London have been carried out without the subscribers appreciating that anything exceptional had been done at all, and certainly without any reflex action on the area as a whole. Mr. Stubbs thought that it might be preferable from the economical engineering point of view to try to utilize the existing plant to a much greater extent, and the author touches upon this in Fig. 2 where he deals with limited plant conditions. I am quite sure, however, that, wherever it can be done at reasonable capital expenditure, it is much better from the service point of view to have the cables brought right into the new exchanges. The testing out is much facilitated and there is much less chance of anything going wrong at the time of transfer. Mr. Bryant mentioned, I think, that if it is possible to have all the connections at the new exchange working in parallel with the old exchange some week or so beforehand, trouble at the actual time of transfer was almost entirely removed. This was done in the case of Victoria Exchange and all the most successful transfers, and the changes from one switchboard to the other were made with little or no trouble to the public. Throughout the period involved, which is often of necessity considerable, the engineering and traffic staffs should be in the closest co-operation: there should be the fullest understanding as to the methods to be employed, and all the details should be discussed very fully by both sides. The temporary interruption of circuits sometimes causes an extraordinary amount of trouble, and it is really a very important part of the duty of the engineer in charge to ensure that his staff does appreciate the service point of view. In this connection I should not like the author to think that I am adversely criticizing the present co-operative effort. The fact that in recent cases the quality of service on the new exchange has been of a higher order than that on the old from the first day of opening is, I think, proof to the contrary. The author has not dealt very closely with correction of area transfers, which become a problem of magnitude in large cities developing rapidly. Most of the procedure and organization detailed by him will apply in such cases. The importance of special attention to junction and particularly the subsidiary circuits might have been emphasized. If faults occur on the busy-back, tone test, supervisors' or inquiry lines, quite a disproportionate amount of service trouble is caused.

Mr. B. O. Anson: The great value of the paper to my mind lies in the emphasis laid upon the need for devoting attention to details of organization. It is also valuable in respect of its treatment of line alterations. The apparatus requirements in connection with exchange transfers have of late years been well understood, but the same cannot be said as regards line work and organization. Several speakers have drawn attention to the disadvantages involved in the use of fibre separators placed between the contacts of relays, and it should be mentioned that the use of wooden wedges is standard practice, such wedges being inserted not between the contacts but between the armature and the coil. No doubt as regards changes of line plant, the most difficult conditions arise in cases where there is a limited amount of cable plant between the old and new exchanges and it is impossible or inadvisable to draw-in either permanent or temporary additional cables between these points. In such a case, of course, the natural procedure would be to use change-over frames, and where this can be done experience proves it to be a reliable, speedy, and accurate means of effecting the transfer. Sometimes, however, there is difficulty in finding accommodation for the large number of change-over frames that may be needed in connection with a big exchange, and in that case probably the expedient suggested by Mr. Laidlaw should receive consideration, that is to say, the subscribers should be canvassed and those which need service during the week-end should be placed upon change-over frames, leaving the remainder to be catered for by plumbing and jointing work. This latter method of course cannot be expected to produce such noticeable freedom from faults as that of the change-over frame method, and when it is realized that in all work of this kind the engineer places a " bottle-neck " responsibility upon one man (the jointer), the necessity for judiciously selecting that man arises. The same is true even when change-over frames are used, although the work in that case being spread over a longer period of time and involving more operations the faults that arise are not so conspicuous, though they are none the less real. For such reasons, therefore, I am of opinion that the making of a through joint during the week-end upon a limited number of circuits under conditions such that the jointer can work with precision and comfort, should not be ruled out of court arbitrarily. In connection with the introduction of automatic exchanges (in which I am more particularly concerned), it is interesting to note that there is some departure from the arrangements usually made when subscribers at a magneto exchange are transferred to central battery working. In the latter case it is customary to leave the magneto apparatus in operation until after the change-over, modifying the direct lines by fitting condensers and in the case of private branch exchanges by fitting holding keys and such other subsidiary apparatus as may be required in connection with central battery signalling. In automatic working it is of course necessary at the outset for the subscribers to be provided with an instrument that has a dial, and this entails a more complete treatment of the subscribers' apparatus. As regards direct lines, it was at one time the practice to insert a two-way switch in the line circuit, leaving instructions with the subscriber to turn the switch at a pre-arranged time upon a given date. This involved considerable trouble not merely because the subscribers failed to turn the switch but also because of wiring faults that occurred at the switch itself. Mr. Hedley recently introduced the method of

fitting the new telephone permanently wired in its permanent position and connecting the old telephone to the line via temporary leads. The bell circuit of the old telephone is left disconnected so that during the transition period the ring is received upon the bell of the new instrument. As regards private branch exchange switchboards, it is now the custom at automatic exchange transfers for the permanent central battery switchboards to be fitted before the transfer, temporary arrangements having been made for the supply of speaking and signalling current between the fitting of the switchboard and the transfer of the main exchange. These arrangements are quite successful in practice, and are advantageous inasmuch as the bulk of the work is performed before the transfer takes place and the visits of workmen are reduced to a minimum.

Mr. A. F. Harmer : Attention has been drawn to-night to the difference between heavy and telephone engineering. My experience as a " heavy " engineer has been that station engineers generally consider that anything is good enough for, and have in fact a contempt for, telephony. They do not appear to realize that a telephone system controlling power main and substations should be carried out with as much or even more care than the power circuits themselves.

Mr. J. Hedley : I was glad to see that the objections inherent to the transfer of lines, either singly or in groups, was brought under notice in the opening part of the paper. Simultaneous transfer of lines is almost invariably a practical proposition, and much useless engineering work is avoided when that course is followed. An instance of this came under my notice recently. Two exchanges in the same town were to be replaced by a new exchange, and a suggestion was made to transfer the subscribers from the two exchanges in two operations. An investigation of the conditions proved that there was no justification for such procedure, in fact a saving of some thousands of pounds resulted by carrying out the transfer of the two exchanges simultaneously. With regard to the line-plant alterations, the " teed " underground and overhead method, and " grouped lines " scheme, are the two standard arrangements in the Post Office ; the latter method is followed wherever possible, as much economy results in cable plant. In a recent case investigated, the " teed " arrangement was suggested throughout ; upon inquiry it was found to be possible to overcome the difficulties anticipated with the " grouped lines " scheme, which resulted in a considerable reduction in the number of ducts and cables required between the two exchanges, and a saving of several thousands of pounds. I quite agree with the author that teeing of lines at the old exchange is undesirable. I should like him to quote instances where he considers such a course may be necessary, as inferred ; it is difficult to conceive of any conditions which would justify such an arrangement. After the transfer, the lines must of necessity be joined straight through at some point or points externally, and to avoid wiring difficulties and circuit interruptions subsequently, it is preferable that the lines concerned be dealt with prior to the transfer. The author appears to recommend diverting the lines via the new exchange whenever possible. The scheme necessitates twice the number of cable pairs entering the exchange, relative to the number of subscribers' circuits concerned, and it is difficult to understand under what circumstances the increased cost of the cable and exchange plant required could be justified in preference to teeing the lines externally. Perhaps the author can furnish details justifying the adoption of this scheme in some particular case. The diagrams of the teed connections in underground cables are very clear ; similar sketches showing the arrangements required with the " grouped lines " scheme would also be useful. It will be seen from Fig. 7 that the line passing the new exchange has to be intercepted and cabled via a break-jack in the new exchange prior to the transfer. A sketch showing the method of cutting in, and the sequence of operations to be followed to prevent interruption, would be helpful. In the manhole outside the old exchange, the physical connection of the two subscribers' lines concerned has also to be effected after the transfer. To avoid circuit interruptions, it is essential that the numbering of these two lines in the manhole should be carried out prior to the transfer ; the insulated wires of the circuits can also be connected in advance so that the straight-through joint can be made subsequently without difficulty. A diagram indicating the various stages of such arrangements would also be useful. With regard to the arrangements to be made in subscribers' offices, I think Mr. Anson gave the impression that I was responsible for introducing the method of teeing the old and new telephone. I was probably responsible for introducing it into the Post Office, but I think it was first adopted in America so far as direct lines are concerned. In my opinion the scheme has many advantages. The expenditure involved in putting the condenser in the bell circuit of the magneto instrument and testing for the polarity of the receiver is obviated. The whole of the internal wiring, etc., required in the subscriber's office can be carried out when fitting the new telephone, i.e. one visit only is needed to carry out the installation work, and a second visit after the transfer to recover merely the old telephone. There has been some development introduced by the Post Office in connection with private branch exchange installations. It is now possible to arrange for the common battery feeding current on the private branch exchange circuits to be fitted at the old exchange, instead of at subscribers' offices, consequently all installation and recovery work necessary at subscribers' offices can be affected with one visit only, thus reducing the labour costs appreciably.

Mr. C. Beaver : I should like to join issue with a previous speaker who referred to the contempt which heavy engineers are supposed to feel for telephone engineers. I am sure there is nothing of the kind. I think it is rather the sort of respect which is born of ignorance of the subject, and I believe that the days of intolerant contempt of one branch of the electrical profession for another branch have entirely vanished.

Mr. W. Noble (*communicated*) : On page 390 three methods of effecting transfers are indicated. If method (*a*) or (*b*) were adopted the actual transfer would extend over a more or less considerable period of time during

which intercommunication would have to be maintained. For a period there would be two exchanges instead of one. On the old exchange the number of lines would be a gradually decreasing quantity, whilst on the new it would be increasing. At the commencement of operations subscribers A and B would both be connected to the old exchange, and at the end of the operation both would be joined to the new exchange; but for a period A and B would be connected to two different exchanges. Ordinarily the connection of A and B would involve only the services of one operator and one pair of cords. During the transition period, however, the process of connecting A to B would require the services of two operators and a junction circuit between the exchanges, and all the time that the changes were taking place the operators at both exchanges would have to know which subscribers were connected to the one exchange and which to the other. Thus a transfer long drawn out in time involves extra labour, plant, and organization. By the adoption of method (*c*), the operation of the old exchange ceases totally at a definite instant; the new exchange comes into use at the same moment, and there being no overlap the extras are avoided. This is the method always adopted by the Post Office. Usually the change-over takes place after business houses close on Saturday, thus allowing a week-end for clearing any defects. With regard to the line arrangements described on pages 391 and 392, the teeing arrangement is the one most commonly adopted, at least in connection with the transfer of large exchanges. The tees are not necessarily made all at one point. It may be more convenient and economical to make them at various points, much depending of course upon the character and lay-out of the line plant. The tees, however, should not be made at the old exchange or at any other temporary point; they should be made at points where the lines will be permanently connected through to the new exchange, for by so doing interruptions to working circuits will be avoided when the tees to the old exchange are cleared away. As instances of cases where all the lines were diverted by teeing, the Victoria Exchange, London, and the Central Exchange, Manchester, might be named. It is often desirable to deal with a portion of the plant in the manner indicated in Fig. 1 (*d*), the transfer of the Central Exchange, Glasgow, from the old Municipal Exchange to the Post Office building in Waterloo-street being a case in which the arrangement was adopted to a considerable extent. The arrangements to be made by this method are rather more complicated than are those involved by the simple teeing scheme, but the objections to the system are of much smaller magnitude than the author of the paper seems to think. If proper arrangements are made before the transfer takes place for the ultimate jointing of the cables, the work can be, and in fact is, carried through without interruption to the service. As described on page 392 it is usual to disconnect the working lines at the old exchange by withdrawing the heat coils. Occasionally difficulties are encountered which make the adoption of other means desirable, and in a recent case of a large transfer it was considered necessary to effect the disconnection by inserting insulating pegs into the test jacks shown on page 393. The relays shown in Figs. 3 and 4 are of the Western Electric Company's type; the method of disconnecting the exchange plant at the cut-off relays by means of fibre separators placed between the contacts has been employed, but the same object may be obtained by inserting small wooden wedges between the relay coils and armatures. In the case of relays of the type originated by the Peel-Conner Company, the disconnection is effected by passing small metal clips over the ends of the relay cores and armatures. The clips are tied together by tapes and are removed in groups when the transfer is effected. The type of protective device shown in Fig. 5 is not used for subscribers' lines in Post Office manual exchanges. The arrangement shown in Fig. 6 has never been used by the Post Office, and if it were found advisable in any particular case to adopt the principle it is probable that a device in the nature of a jack would be substituted for the temporary protector. Fig. 7 does not show the standard Post Office arrangement; a special jack designed for the purpose is used in place of the temporary protector at the new exchange. As regards junctions, it is not Post Office practice to pass all circuits of that description through break-jacks, and therefore Fig. 8 is not in accordance with Post Office arrangements. It is indicated towards the end of the paper that selected groups of junctions are transferred in advance of the general transfer, during and after which the remaining junctions are dealt with. At the new exchange the transfer is effected by inserting the heat coils, while at the old one it is effected either by withdrawing the heat coils or by inserting insulating pegs in the break-jacks if such form a part of the old equipment. In regard to the statement at the top of the second column on page 400, when a magneto exchange is to be replaced by a common battery manual plant it is usual to "modify existing apparatus to permit of central battery working until the modern central battery apparatus is installed after the transfer." When the new exchange is of an automatic type, however, the new subscriber's apparatus must be fitted and ready for use before the transfer takes place. The old telephone remains till after the transfer, and thus for a period each subscriber's station is fitted with two telephones. No difficulty or trouble has been experienced with the dual equipment of stations, and there is reason to suppose that it would be economical to adopt a similar scheme when transferring from magneto to common battery. The adaptation of either instrument would be avoided. A change-over switch to be operated by the subscriber at the time of transfer is not necessary. The two telephones would be connected to the line in multiple with the bell of the magneto set disconnected. The subscriber would be instructed to use the magneto telephone until a certain day and hour and the common battery set thereafter. If he continued to use the magneto set after the transfer no harm would be done.

Mr. F. G. C. Baldwin (*in reply*): It is a matter of gratification that so many matters of interest which had to be excluded from the paper owing to the broad field covered by it have been supplied in the discussion. Many of the questions raised are of a similar nature

and are so closely related that it will perhaps be better to reply to them collectively.

Line plant arrangements.—The lay-out of the existing line plant is generally the main factor governing the choice of a method for transfer. It is not, in my opinion, desirable to adopt a fixed rule or to regard any single method as a standard. Each case should, I consider, be decided on its merits. Frequently two or more of the methods explained must be employed in a particular transfer, but for purposes of comparison each available method has been treated independently in the paper. Although it is not desired to suggest that the method illustrated in Fig. 1 (*d*) and Fig. 7 should not be regarded as a recognized procedure, its adoption should not be decided upon until the alternative methods have received careful consideration. I would have no hesitation in giving preference to any

The method is particularly applicable to cases where the new and old exchanges are widely separated and where approximately one half the group of subscribers' lines to be transferred passes in close proximity to the new exchange, a condition which seldom obtains, and is therefore suitable only for comparatively few cases. Theoretically the arrangement is an attractive one, but from actual experience I am convinced that the disadvantages given on page 392 of the paper have by no means been overstated. Mr. Hedley mentions that in one case the adoption of the method resulted in a saving of several thousands of pounds, presumably capital expenditure, but he does not state what the additional cost of transfer amounted to.

The question of teeing at the old exchange some of the lines to be transferred refers only to those isolated cases where satisfactory conditions near the old exchange

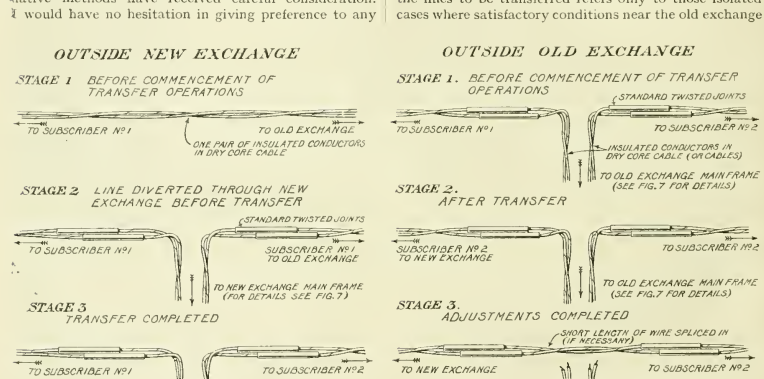

OUTSIDE NEW EXCHANGE
STAGE 1 BEFORE COMMENCEMENT OF TRANSFER OPERATIONS
TO SUBSCRIBER No 1
TO OLD EXCHANGE
ONE PAIR OF INSULATED CONDUCTORS IN DRY CORE CABLE
STAGE 2 LINE DIVERTED THROUGH NEW EXCHANGE BEFORE TRANSFER
STANDARD TWISTED JOINTS
TO SUBSCRIBER No 1
SUBSCRIBER No 1 TO OLD EXCHANGE
TO NEW EXCHANGE MAIN FRAME (FOR DETAILS SEE FIG. 7)
STAGE 3 TRANSFER COMPLETED
TO SUBSCRIBER No 1
TO SUBSCRIBER No 2
TO NEW EXCHANGE MAIN FRAME
OUTSIDE OLD EXCHANGE
STAGE 1. BEFORE COMMENCEMENT OF TRANSFER OPERATIONS
STANDARD TWISTED JOINTS
TO SUBSCRIBER No 1
TO SUBSCRIBER No 2
INSULATED CONDUCTORS IN DRY CORE CABLE (OR CABLES)
TO OLD EXCHANGE MAIN FRAME (SEE FIG. 7 FOR DETAILS)
STAGE 2. AFTER TRANSFER
SUBSCRIBER No 2 TO NEW EXCHANGE
TO SUBSCRIBER No 2
TO OLD EXCHANGE MAIN FRAME (SEE FIG. 7 FOR DETAILS)
STAGE 3. ADJUSTMENTS COMPLETED
SHORT LENGTH OF WIRE SPLICED IN (IF NECESSARY)
TO NEW EXCHANGE
TO SUBSCRIBER No 2
DISCARDED CONDUCTORS TO OLD EXCHANGE

FIG. A.—Operations necessary at cutting-in points outside new and old exchanges when method illustrated in Fig. 7 is adopted.

of the others which have been dealt with in the paper if there were no material difference in cost. Usually the only claim in its favour is a saving of the capital cost in the installation of cable plant which would otherwise be necessary to permit of the transfer being effected. Mr. Laidlaw has stated that while the method is especially good, it is expensive; but presumably he refers chiefly to the labour cost of the preparations for transfer and of restoring the affected plant afterwards, and if this be the case, I quite agree with him. The extra costs entailed by the method spread over the period of preparation for transfer and subsequent restoration of plant, extending over a period of sometimes from six to twelve months or even longer, are so high that they may exceed the annual charges for the additional cables required in either of the alternative methods. This point is brought out very clearly by Mr. Byng.

for economical teeing are absent owing to congestion prior to transfer, and where facilities are afforded for cutting out from the old exchange after the plant thrown spare has been recovered. In cases of this kind, which Mr. Hedley agrees are undesirable, the work of cutting out lines from the old exchange after transfer is no more than would be necessary where the method illustrated in Fig. 1 (*d*) and Fig. 7 has been utilized.

In response to Mr. Hedley's request for a particular instance where adoption of the method illustrated in Fig. 1 (*c*) and Fig. 6* would be justified, the following particulars are taken from an actual case. Before

* In the discussion at Manchester (see page 422) attention was directed to the fact that all the methods of transfer mentioned in the paper had been used in connection with one particular transfer, approximately half the total circuits to be transferred being dealt with in the manner indicated in Fig. 1 (*c*) and Fig. 6.

operations were commenced, the circuits to be transferred were conveyed into the old exchange approximately as follows :—

By means of underground cables ..	280 circuits.
By means of overhead cables ..	500 circuits.
By means of open wires	100 circuits.
Total number of circuits to be transferred, 880.	

It will be obvious that the only practicable alternative to that of diverting the lines through the new exchange prior to transfer is to tee at the new distributing points the whole of the lines carried by overhead means, so that they may be available at the new exchange. Such a large number of overhead tees would be both difficult and costly to make and maintain and, what is even of greater moment, would necessitate a large and undesirable amount of work on the overhead lines after the transfer.

Cases where the line-plant conditions are particularly favourable to the adoption of this arrangement are those like the one mentioned above, where the existing line-plant system is largely overhead from the old exchange and where, as indicated in the paper, an entirely new underground system, or considerable augmentation of the existing cable system, is to be embarked upon in association with the transfer to new premises. This is a condition frequently met with in this country at the present time.

It does not necessarily follow that twice the number of cable pairs relative to the number of subscribers concerned must be led into the new exchange specially to admit of the transfer being made. Nowadays, new cable plant is installed on the basis of provision for future requirements for a lengthy period, and consequently a large proportion of spare pairs are available for accommodating the lines between the two exchanges until the transfer has been made.

If Mr. Hedley's suggestion has been rightly interpreted, the diagram reproduced herewith (see Fig. A) should give the desired further particulars regarding the jointing operations which are necessary in the near vicinity of the old and new exchanges. The diagram should be read in conjunction with Fig. 1 (*d*) and Fig. 7. Although it is agreed that preparations for the through joint, or joints, near the old exchange should be forwarded as far as possible before the transfer, the actual jointing of the conductors must of course be left until the transfer has been carried out.

Means for effecting transfers.—The use of a wooden wedge in place of the fibre separator described in the paper has been referred to by Mr. Noble in his written communication, and by Mr. Moir and other speakers. Although I have not experienced any trouble whatever from the use of hard and smooth fibre separators in the manner described, it is certainly desirable, if possible, to avoid the introduction of any foreign substance between relay contacts, and in this sense the use of a wood wedge is preferable. If, however, the wedges be placed between the springs there is danger that the springs may inadvertently or carelessly be strained and the adjustment of the relay affected. If the wedge be placed between the armature and the coil of the relay, this possibility is avoided, but the wedges are liable to fall out of place.

Interference with the cut-off relays can be altogether avoided by using insulating plugs in the special form of protector shown in Fig. 5 of the paper, where such protectors are fitted, with the disadvantage mentioned by Mr. Edmonds and Mr. Bryant, that the two exchanges cannot be thrown in parallel for a period immediately prior to transfer. In the small exchanges, apart from automatic, where these protectors are fitted, this disadvantage is not perhaps of much moment, as the amount of testing to be done will not be heavy and can be undertaken comfortably at the test desk.

The reason for utilizing in Figs. 6 and 7 a temporary or spare protector is that the lines concerned may be much more rapidly disconnected by the withdrawal of heat coils than by the insertion of insulating plugs.

Treatment of junction lines, order wires, etc.—The transfer of junction lines has been only briefly touched upon. As intimated by Mr. Laidlaw, it is not always the case that break-jacks are provided for all junctions entering an exchange, but in some cases where the number of junctions is small, break-jacks are available on the main distributing frame and may then be utilized with advantage. Where the number of junctions is high, insulating plugs may be inserted or heat coils may be withdrawn at the old exchange to disconnect from the old equipment, and heat coils inserted at the new exchange to connect the circuit to the new switchboard as described by Mr. Noble. These means are somewhat slow in operation and, if desired, temporary break-jacks may be specially fitted for the purpose. It is doubtful, however, whether the expense is justified.

Mr. Edmonds has drawn attention to the omission to emphasize in the paper the importance of junction lines, order wires, busy-back and tone-test circuits, etc. Such circuits are of course of special importance and should be treated accordingly. If circumstances permit, it is preferable to provide as many of these special circuits as possible in advance, in order that they may be proved to be in complete working order in readiness for the transfer and so avoid the possibility of trouble when brought into use.

Transfers to automatic exchanges.—Automatic exchanges have not been specifically mentioned but, generally speaking, the principles included in the paper are applicable to transfers in the case of most, if not all automatic systems.

General.—Mr. Harmer suggests that station engineers consider anything to be good enough in telephone engineering and that they appear to bear some contempt for telephony. If this be the case, then all I can say is that with the superficial treatment which such contempt would be likely to induce, no telephone system, large or small, could be expected to give satisfaction.

Manchester Local Section, 29 January, 1918.

Mr. W. J. Medlyn: In Fig. 4 the author illustrates the use of insulating separators placed between the contacts of relays of the Western Electric type I had intended to point out that this method is not practicable in the case of relays of the Peel-Conner type which have been installed in a number of large exchanges in recent years, but the author has already dealt with that on the screen. The statement on page 400 that "the displacement of the magneto generator and primary batteries at the subscriber's station renders a complete change of apparatus desirable although not absolutely necessary," is a little ambiguous, but it seems to me to convey the impression that the recovery of the magneto telephone and the fitting of a central battery instrument at the subscriber's station are not matters of very serious moment. It is, of course, possible to work a "condensered" magneto instrument in connection with a central battery exchange, but I think the author will agree that such a combination is very seriously detrimental to maintenance, economy, and efficiency, if intended to be retained permanently or for a prolonged period. It is possible that my reading of it may not be correct, but it is an important point which deserves to have attention. With reference to the three alternatives (page 400) for the treatment of subscribers' installations:—(*a*) The author may be able to state whether the fixing of new central battery apparatus alongside the old, with change-over switches, has ever been tried on an important scale in connection with a change from the magneto system. The arrangement was discussed in this district some time ago, but the conclusion arrived at was that it would be more costly and less convenient than the usual practice of fitting a condenser on each telephone. In the Manchester area, where through-signalling on junction circuits is in operation, every magneto telephone is already "condensered" and no further expense in this connection would therefore be required to change over any of the exchanges to the central battery system. Where a change-over to the automatic system is being effected, the use of a duplicate instrument at the subscriber's station is, however, unavoidable. The reason for this is that the instrument must be fitted so as to provide for the dial arrangement to be brought into use immediately after transfer to the new exchange. (*b*) I do not think it can be agreed that it is economical and convenient to "condenser" existing apparatus in the case of through switches, illustrated in Fig. 15A. The equivalent central battery equipment known as "bell set No. 4" is suitable for either magneto or central battery working, and it is preferable that this be fitted in each case at the outset. If the old switches are not changed as part of the preparatory work, great trouble may be expected, due to false clears, after the transfer to the new exchange. With the apparatus shown in the figure quoted, there is no holding coil, and in practice the absence of this gives rise to trouble unless the exchange is made beforehand. (*c*) The fitting of new central-battery private-branch-exchange switchboards prior to the change-over is not free from objection, and it would be of interest to know whether this has ever been done on an extensive scale. Where such boards are changed beforehand, power must be provided specially from primary batteries, or by means of a power lead, for all speaking and signalling connections, including talking from the extension instruments over the exchange lines. Primary batteries for such a purpose are expensive, and I think it would generally be inconvenient to provide power leads in advance of the change-over. The circumstances depend upon the lay-out of the line plant. Sometimes power leads can be provided; sometimes their provision would involve a lot of expense. After the transfer, power for conversations over the exchange line is automatically supplied from the exchange battery, and the standard of speech transmission is adjusted on this basis. Under the more variable temporary conditions during the transitional period, therefore, complaints would be liable to arise in maintaining satisfactory speech for long-distance working. Further, prior to the change-over no extension could clear through to the exchange unless the magneto instruments were left in position, and even then the ring-off signal to the main exchange would be rendered unsatisfactory through the effect of the shunt fitted on the new central-battery private-branch-exchange switchboard. If the magneto instruments are recovered, the private-branch-exchange operator must ring back on every exchange connection to clear; but as the observance of this practice is more easily desired than secured, the percentage of "subscriber fails to clear" would undoubtedly rise in the old magneto exchange and I think serious traffic troubles would be caused at an important centre. It seems to me that is a matter of considerable importance and it would interest many of us to know whether such switchboards have been changed on an extensive scale in any case. From the remarks on page 404 it would appear that the making of certain tests at least three times is recommended, and I think it would be of interest to know whether the author has found this elaboration really necessary in his experience. Repetition of tests no doubt tends to the elimination of faults before the change-over, but it might be difficult to show that the results obtained would justify the expense of over-elaboration. I may say our experience in Manchester did not appear to indicate that all this expense was necessary. Rehearsal is referred to in item 13 under "final preparation" (page 405), but the author has omitted to say that in the Post Office it is the practice to give each man a typed schedule telling him exactly what he has to do. He has indicated by his remarks that a programme is prepared for the operating staff, and I suggest that it is an inadvertent omission not to state that instructions in writing are given to the engineering workmen so that there may be no mistake. In conclusion, it may be of interest to state that last year we had an important transfer of the Central Exchange magneto and call-key system to new central battery equipment in Manchester, the new exchange being about 400 yards

distant from the old premises. The work involved the transfer of 4,045 subscribers' lines, 1,426 local junctions, 108 junctions from the Manchester trunk exchange, and 400 private wires, a total of about 6,000 lines. Simultaneously with the transfer, a "no delay" service between Manchester Central and City Exchanges and 39 trunk centres within a radius of about 35 miles was brought into operation by the joining up of 539 tandem junctions. The local service cables were mainly made up of 200 to 800 pairs, and the joints made on these cables in the street manholes totalled nearly a quarter of a million. In preparing for the transfer about 75 per cent of the circuits were looped into the new exchange and 25 per cent provided for with tee joints. In Manchester, Whit-week is the slackest traffic period of the year, and fortunately we were able to fix that time for the change-over. It was effected very satisfactorily; we had nothing in the nature of confusion and the operations worked quite smoothly. We were favoured by the traffic conditions during the Whitsuntide holidays.

Mr. G. S. Wallace: On reading the paper the first thing that struck me was that a transfer from magneto to central battery had been selected although conversions from magneto or central battery to automatic working are now looked upon as more up-to-date. The author has, I think, decided rightly in this matter. At the bottom of page 390 he refers to "transferring each line independently," but I am not clear as to what he has in mind. One can understand transferring subscribers' lines in groups, as mentioned under (*b*)—the City Exchange, Manchester, is an example of this—but to transfer each line independently does not seem to be a proposition that could be entertained for a moment under any conditions. At the end of page 392, in connection with "methods of effecting transfer," the disconnection of the old exchange is effected by withdrawing the heat coils, although, as shown in Fig. 3, test jacks are available So far as large exchanges are concerned I find myself in disagreement with the author on this point. Heat coils (as shown in Figs. 4 and 5) are very small and troublesome pieces of apparatus at the best, and when they are springing out of the strips of arresters in thousands a number of them get wedged in amongst the arresters, causing faults which are difficult to locate readily. Speaking from my own experience and latest practice I much prefer to isolate the old exchange by inserting wooden wedges between the springs of the test jacks. The time it would take to do this at the actual cut-over could, as was done at Manchester, be reduced very considerably by wedging up, prior to the opening of the new exchange, the lines of all subscribers whose offices were known to be closed. This was very simply arranged in Manchester. We obtained from the traffic section a list as complete as possible of all lines which were likely to be out of use. The cut-over took place about 2 o'clock. About 1 o'clock the test clerks cut out all the subscribers whose names appeared on these lists. Consequently when they came to cut out and isolate the rest of the exchange it only meant inserting a few hundred plugs. Furthermore, by disconnecting at the test case the necessity for withdrawing, cleaning, and replacing some 10,000 sets of carbon blocks and mica separators was avoided and much expense and interruption to the service was saved. It is well known that the less carbon arresters and mica separators are interfered with the better the telephone service will be; and if cleaning is found to be necessary I would suggest that, as is done in Manchester at present, it would be preferable to clean the arresters *in situ* by means of a vacuum cleaner rather than have to take out and replace each one separately. Regarding preparatory work at substations (page 400), I agree with the author that it is better to modify the subscriber's magneto instrument than to fit a central battery instrument either with or without a change-over switch alongside it. It is difficult to avoid the second instrument when the change is from magneto to automatic working, but as described by the author it can be readily done with a central battery conversion. It has its disadvantages, of course, but it can be done to a certain extent. In the last paragraph on page 401 there is a somewhat important omission, as I find no mention of a test to ascertain the conductor resistance of the subscriber's line. It will readily be seen that in a central battery system where the battery current for each subscriber's transmitter is drawn over the line from the main exchange, any circuit which offers a higher resistance than the maximum transmission limit of 500 ohms will be adversely affected from a transmission point of view, and if the resistance is very high the tripping relays in the ringing circuit or the relays which operate the clearing lamp signals may fail to act. The earlier that cases of this kind are brought to the notice of the engineer responsible for the line plant, the less chance will there be of the transfer being delayed, and this test should not be left until the final preparations referred to on page 404 (Fig. 20). Another point which does not seem to have been given the prominence it deserves is the modification of the apparatus on the junction circuits at the exchanges, both trunk and local, which will work to the new exchange. Apart from the expense of the additional junction equipment and the difficulty that is usually experienced in finding accommodation for the same on the switch sections at the sub-exchanges, the amount of work entailed in modifying the circuits and testing them is out of all proportion to what is necessary in the case of subscribers' apparatus. As a matter of fact the junction arrangements for the transfer of subscribers from the Central to the City Exchange in 1909 necessitated the provision of entirely new switch sections, the removal of the switchroom at four of the sub-exchanges, and the provision of additional "B" sections at several other exchanges. Some idea also of the worry and anxiety thrown upon the testing officers who are responsible for this branch of the transfer can be formed when I mention that in connection with the recent transfer of the Central Exchange from Portland-street to York-street no less than 64 other exchanges were involved, and over 1,000 trunk and junction circuits had to be modified and tested out without interfering with the telephone traffic to and from any of the exchanges concerned. It is not the transfer of the local subscribers' lines but the transfer

of the trunks and junctions which is so important, and the author barely refers to the matter at all, omitting it altogether from the scheme of operations shown in Fig. 24. As regards the installation of the new exchange plant (page 403), I desire to lay stress upon the absolute necessity of a thorough examination of all material and a rigorous test of all electrical equipment as it is being installed, either by contractors or the local officials. Unless this is done by competent and reliable officers, not only will breakdowns occur on the opening day, but the exchange faultsmen will be constantly lifting up heavy masses of switchboard cabling to repair faults due to badly soldered wires, faulty springs, and other troubles too numerous to mention. I should like also to refer to the last paragraph but one of the paper, where the author says it is advisable that complete control of the transfer should be vested in one individual stationed preferably at or near the test clerk's desk. Under existing conditions in the Post Office, where the traffic branch, internal, and external sections, whilst working in close co-operation with each other have their separate organizations, it would be interesting to know whom the author has in his mind as the controlling officer. It is surely not the intention, as suggested on page 406, to put the test clerk at the new exchange in that position. He is only one link in the chain of operations, and where a large exchange transfer is concerned such an arrangement would not give satisfactory results. The controlling arrangements adopted at the recent Central Exchange transfer were on a co-operative basis. They worked smoothly and well and can be recommended in cases where single control is not available. Prior to the change-over the chief officers of the three sections previously mentioned arranged the duties of their respective staffs and exchanged schedules. In the earlier stages of the change-over the main centre of control was a table in the new switchroom, from which point the traffic superintendent and equipment engineer, working in the closest co-operation, controlled the operations of their respective staffs at the old and new exchanges until such time as the whole of the local and junction circuits were transferred and the old exchange was isolated. In the meantime, of course, the operators were proceeding with the work of calling up subscribers on the exchange. The centre of control then passed to the test desks in the new exchange, the external engineer dealing with any line-plant troubles reported by the test clerks, and the internal engineer with all exchange equipment troubles or faults on subscribers' apparatus.

Mr. G. F. Staite: The author has dealt with the subject mainly from an engineering point of view, but I am going to make some comment upon it from a traffic point of view. The author has indicated in a general way some of the more important traffic and operating considerations, but they do not by any means comprise the whole of the traffic considerations, and in fact these are so many and varied that it would not be possible even to enumerate them in a short space of time. I propose to comment on one or two of the points dealt with by him.

Choice of day and time for transfer.—The incidence of the telephone traffic load is of a very consistent character, and for this reason it is possible to estimate many months in advance what the amount of traffic will be at a particular time. This permits a day and hour for the proposed transfer to be fixed sufficiently far ahead to enable the preparatory work to be carried out. The actual hour of the transfer is not usually definitely fixed until shortly before the day, but generally there is no doubt in anyone's mind as to approximately what that hour will be. This time is usually at the commencement of a period of light traffic, frequently that which occurs between about midday on Saturday and the following Monday morning. There is an obvious advantage in making the actual change as early in this period as traffic will permit, in order that the period of slackness following the transfer may be as long as possible and thus provide the greatest margin of safety.

Switchboard distribution of subscribers' lines.—This is a most important consideration. On it depends to a large extent the quality of the service which will be given to the subscribers in the new exchange. The main object of the distribution is that the resulting load on the operating positions may be evenly distributed, and to enable this to be done it is necessary that the number of calls which will be made by each subscriber should be known. Not only must the number of calls be known but their character, because the operation of some calls involves more labour than that of others, and in fixing the load we are concerned, with the amount of labour rather than with the number of calls. These two things generally bear a fairly definite relation one with the other in the aggregate, but the variations on the individual subscribers' lines are considerable, and these have to be taken into account when estimating the amount of labour involved in their connection. One of the things we seek to avoid is the changing of subscribers' numbers, but it is rarely possible to carry out a transfer of any magnitude without some changes. There are quite a number of considerations which go to the selection of the new number for a subscriber when a change becomes imperative. These selections must necessarily be made far in advance of the actual date of the transfer, and to avoid confusion during the preparatory period great care is taken to preserve their secrecy until immediately before the transfer, when the subscribers concerned are advised as to their new numbers. While we seek to avoid changing numbers it should not be concluded that such changes are bad from the subscriber's point of view. It is generally the Post Office which suffers The inconvenience of dealing with calls to changed numbers is theirs, but so far as the subscriber himself is concerned no traffic disability is occasioned; in fact it is generally the other way, because numbers are only changed when the traffic considerations show that a desirable improvement in the handling of the traffic will result. There is an exception to this statement, namely, that on occasions the engineering necessities require that numbers should be changed, but the rule still holds good that the subscriber suffers no traffic disability.

Training of operators.—Much depends on the proper

training of operators, and when the proposed transfer is on a large scale and involves a change of system from, say, magneto to central battery, arrangements must be made to instruct a large staff in the new working in such a way that they must be thoroughly proficient at the date of the transfer without detrimentally affecting the service during the preparatory period. It will be obvious that we cannot withdraw a large proportion of the staff at any one time, and therefore the training must extend over a considerable period. One of the dangers to be guarded against is that those who undergo the course of tuition, which is carefully prepared and is given in an operating school apart from the exchange, shall not forget anything they have learnt by the time of the transfer. To convert one who is expert in operating a switchboard of the magneto type into an equally expert operator of the central battery type requires in each individual case a substantial period of training. A good plan is to divide the period into two. The first period would be the main one and would comprise the whole subject. The subsequent period, which would be as near to the transfer as possible, would be in the nature of a refresher and need only be short. This course of training should be supplemented, if possible, by a period of actual switching experience in a central battery exchange, and by visits to the new exchange when the equipment has been completed and shortly before the transfer.

One could say much on traffic and operating considerations, but I do not wish to take up more time on these points. I do, however, wish to refer to one other point and that is the desirability of close co-operation between the engineering and traffic branches when a work of this kind is in contemplation or in progress. These two branches are working along different lines with the same object in view, the object being a successful termination of the many months of work which has been necessary to prepare for the transfer. One good means of securing co-operation is to arrange meetings at which can be gathered together the principal engineering and traffic officers concerned with the work. Free discussion of difficulties and points of doubt will often result in a solution which will satisfy both the engineering and traffic conditions more readily than could perhaps be attained by any other means. Another advantage of such conferring together is that it enables both branches to focus their own ideas and the traffic branch is more able to state its requirements clearly, and similarly the engineering branch more clearly sees in what way the traffic requirements can best be met. In addition to meeting in conference from time to time, the engineering and traffic officers concerned with particular details of the work should keep in close touch. Face to face discussion should be encouraged and by this method much waste of ink and time saved in correspondence. The author refers to the work of preparation for the transfer of a large exchange as extending over many months. While this aptly describes the period of preparatory work the actual considerations involved in a large transfer might be considered to commence some years before the actual transfer takes place. From the inception of the idea I would have the traffic and engineering branches come together and not merely during the period of active preparatory work. Manchester has recently accomplished a work of the character described in this paper, which might be fittingly described as of the first magnitude. Because of certain accompanying works which do not perhaps come within the scope of this paper, the transfer was one of exceptional magnitude, and of its kind one of the most important the Post Office has so far carried through. This was the transfer of the subscribers of the Manchester Central Exchange in the early part of last year. The change-over occupied a period of just under 10 minutes. A few minutes in advance of the engineering cut-over the old exchange ceased work, except that the existing conversations which were in progress at that time were carried to completion. Less than 10 minutes after the word had been given that the old exchange was clear of traffic the new central battery exchange with some 4,000 subscribers' lines and 1,500 trunks and junctions was in full working order, and subscribers' traffic was being handled in the ordinary course. During that short period of time simultaneous changes took place at some 70 exchanges in Manchester and the surrounding Lancashire towns, all of which changes were successfully accomplished. This satisfactory termination of the many months of preparatory work was in no small measure due to the effective co-operation of the engineering and traffic branches, and I should like to see, and I know many engineering officers will agree with me, a close and effective co-operation between the two branches regarded as a recognized part of the organization for dealing with works of the kind described in the paper.

Mr. J. Shea: There are a few points that I wish to bring forward. First, in connection with teeing and looping underground circuits. It is thought that in addition to the items mentioned as being necessary for the use of the jointer at the teeing point, he should also be provided with a telephone circuit to the test room at the old exchange. In regard to jointing, no reference is made in the paper to circuits which test "spare" or on which there is no reply, but which are working circuits such as order-wire junctions, observation and other similar circuits. These must all be tapped out separately with an earthed battery and galvanometer in the manhole to an earthed galvanometer on the old exchange frame, which is a rather more complex operation than the jointing arrangements described in the paper. Numbering the paper sleeves in the joints at the teeing or looping point with the circuit number is not thought to be as good practice as "numbering through" the joint and keeping a record of the circuits working therein, as there is a liability of changes taking place during the period of transition. Tees at Stockport in connection with the transfer have been on for about two years, and there is still no likelihood of the transfer taking place for some time. In this case sufficient spares were teed in to allow of a fair number of new lines and removals, and it has not been found necessary to open any teed joints for the purpose of alterations. The suggestion with regard to beeswaxing of paper insulation and tying up with cotton thread was tried at Stockport, but the constant

handling even with beeswaxing was not altogether successful. The trouble was eventually got over by piecing out the main working joints with silk and cotton tail pieces to be cut out when the teed connections are taken off. All the methods of transferring mentioned in the paper have been used in connection with the transfer at Stockport, in approximately the following proportions. Out of about 1,000 circuits, 150 are teed in the aerial, 250 teed in the underground, 150 break-jack, and the remainder looped into the new exchange. It is apparent, therefore, that very particular records should be kept of the routing of every circuit. Lists were prepared giving the position of lines at the distributing pole, main frame new exchange, and main frame old exchange, number in tee joints, and in other main working joints.

Mr. J. D. W. Stewart: I remember the first transfer of an exchange to central battery working for which I was responsible; it was carried out about 15 years ago. I am reminded of it by the reference the author makes to the use of separators in the line and cut-off relays, which was followed up by Mr. Medlyn. On that occasion we employed cover glasses such as are used in connection with microscopical work. They were inserted where the separators are now placed, and were released by the telephonists plugging into the answering jacks and so actuating the relays. The arrangement worked a great deal better than one might have expected. Mr. Wallace brought out a point which deserves much consideration; I refer to the complexity of junction working in connection with a central battery change. I say central battery change because, after all, that is the change with which we are concerned in almost any transfer. My own experience in connection with junction circuits is that the work which requires to be done at the distant exchanges is a very large proportion, and one of the most important parts, of the work of the engineer in connection with the transfer of a large exchange. There is a little matter in the paper to which I take exception. In his opening sentence the author says, "The development of the art of telephony." I think we shall all agree that telephony has got beyond the "art" stage and that it should be accepted as a science, more or less exact.

Mr. H. H. Harrison: It has been emphasized, perhaps more in the discussion than in the paper, that the great bulk of the work in connection with the transfer of an exchange is in the preparation. The time selected for the transfer is usually Saturday, leaving Sunday for adjustment, and I believe it is the invariable practice to commence cut-over on the Sunday. A curious thing which may be noted is that immediately after the transfer very heavy demands are made on the exchange battery. This is due to various causes. The subscribers have got a new system and are curious to try it; they remove their receiver, without intending to call, they leave the telephone off the hook, the operators are not familiar with the apparatus and do not deal so promptly with calls and, in the case of the automatics, the subscribers are anxious to see how the dial works. So for a short time at all events it is necessary to double the carrying capacity of the battery fuses. The method of providing the protectors with additional springs, which the author describes, is an arrangement that should meet with the approval of telephone engineers. The use of separators at the cut-off relays is very unsatisfactory. They are undesirable principally for two reasons. First of all they tend to interfere with the adjustment of the cut-off relay springs by their forcible introduction and abrupt removal; also the separators are greasy and they pick up dust, which is ultimately rubbed on to the contacts. A further advantage of the protector with the extra springs lies in the fact that the necessity for interfering with the heat coils is removed.

Mr. E. C. McKinnon: Some of the author's statements on page 403 illustrate admirably my personal experience that there is a regrettable lack of organization in the care of new battery plant at telephone exchanges prior to transfers. Instances are not unknown of telephone battery plant being ordered as far ahead as three years before the exchange is open, and in order to adhere to the specified date for delivery, under penalty, the plant may be made and lie at the maker's works for from one to even three years. After delivering the battery at the exchange it is sometimes stored in the basement for months. Eventually when installed in the battery room it is used for carrying out these "exhaustive and methodical tests." These tests are carried on month after month with little consideration of the needs of a new battery, and the common result is that depreciation, or at least temporary deterioration, takes place to the dissatisfaction of all concerned. Obviously the author and his colleagues have brought the problem of transfers to a high state of organization. I recommend that they might with advantage devote serious consideration to the possibility of putting on an equally highly organized basis the systematic care of new battery plant at telephone exchanges prior to putting it into regular service. Further, I suggest—with a view to scheduled organization—that consideration be given to the inevitable overhaul of the battery at some future period, to be carried out in conformity with the Post Office stipulation that telephone traffic is not to be disturbed during the battery overhaul.

Mr. S. Upton: In connection with the use of wooden plugs where test jacks are provided on the main frame, these jacks are undoubtedly a great convenience, and in two of my recent transfers the plugs were improved upon by inserting strips of wood in the continuous strips of test jacks, using plugs only for isolated jacks or groups calling for special treatment. The cut-in can be performed with greater ease with the wooden strips than if a separate plug for each jack were used. I should like to say that I quite agree with the author in his remarks on page 394 regarding a smart transfer. Smartness let there be by all means, but I should certainly say we ought not to be afraid to give ourselves a few minutes' margin if desirable. Mr. Wallace's ideas on the subject of control are, I think, sound. In a transfer of any magnitude, the centre of control must be a shifting point—beginning, say, with the traffic superintendent at the old exchange, it moves along from him to the various engineering and other officers concerned. It is, of course, important that the execu-

tive engineer should have the complete plan of the arrangements clearly in his mind and set out in graphic form before him. On the subject of tee joints, I am not at all in agreement with the author. Personally, after an experience of a large number of transfers, I prefer the tee joint. With one exception (at Kingston-on-Thames, some years ago) I have never found it necessary to leave a tee joint open. Certainly I should not be inclined to treat such a joint with beeswax, because of the troubles likely to result from the waxing, in the way of breakage of the paper insulation, etc., during subsequent operations. Generally speaking, it should always be possible to close down a tee joint by covering the whole with a jacket of sheet lead properly soldered and capable of being pressure tested. I am afraid a fundamental mistake is often made by assuming that a tee arrangement at any manhole must necessarily be a single joint of branches converging at a point. In more than one case I have effected with ease what at first appeared to be a most awkward tee by the use of one or more short lengths of temporary cable trained round the manhole. In such a case, all that is required after the transfer is to cut away the temporary branches, leaving stubs on the distribution cable. As Mr. Medlyn remarked, the fitting of the new subscribers' apparatus by the side of the old is essential when preparing for a transfer to automatic working. We have recently had two transfers to automatic working, viz. Blackburn and Accrington, and our experience has been all in favour of fitting the new apparatus before the transfer, so much so that we have strongly recommended its adoption in transfers to ordinary central battery working. I was rather surprised to hear what Mr. Wallace said about conductivity tests. Has he ever found sufficient high-resistance trouble to warrant the expense of such careful conductivity tests? As regards insulation tests, the author mentions that 100,000 ohms is regarded as a safe figure. Speaking from my own experience, I think 200,000 ohms is as low as we should go. I think it is usual to take meter readings shortly after, not before the transfer.

Mr. H. M. Crellin: As a matter of general interest on the subject, I should like to draw attention to the progressive changes in telephone work, as they appear to me, since I left the National Telephone Company some 15 or 16 years ago. When I left the Manchester exchange in Portland-street, the "call-wire" system was in use, although arrangements were then in hand for converting the whole system to the "lamp calling and clearing" system. In the call-wire system the subscribers were arranged in groups of about 60, each group of 60 being connected to a call wire on which an operator was always listening to receive calls. Each subscriber's instrument was normally connected to the exchange. When a subscriber wanted to effect a call, he depressed a switch which disconnected his instrument from his exchange line and put his instrument directly across the call wire on which the operator was always listening. As the operator did not otherwise know who was calling, it was necessary for the calling subscriber to give both his own number and the number of the subscriber he wished to speak to. The operator then made the necessary connection, replied "through," and the calling subscriber released the call-wire switch, his instrument then being connected (through his exchange line) direct to the subscriber he wanted. So long as there was only one subscriber on the call wire at a time, all was well, but when the busy period of the day commenced (about 11 a.m.) there would be about a dozen subscribers at a time on the call wire, each trying to get his wants supplied first and not above trying to shout the others down; the result was not exactly conducive to smooth working. Since then, it has been completely changed to the "lamp calling and clearing" system, which has, in turn, been discarded in favour of the "central battery" system, and a complete transfer of the exchange, involving many thousands of subscribers' lines, has been made to another building about half a mile away. It speaks volumes for the power of organization possessed by the telephone engineer when he can effect such transfers in a few seconds.

Mr. W. E. Flower: On page 398, alluding to the interference with tee joints and cables, the author states: "To some extent disturbance . . . may be avoided by providing a certain number of spare pairs . . . but this course may not be practicable owing to the limited number of spare circuits available." I do not quite follow why this should be so. The fewer spares there are in proportion to the number of lines in use, the less the relative extra work entailed in teeing them through to the old and new exchanges. In the case of a subscriber ceasing or removing I do not think the joint need be opened at all; there would be no need to disconnect the wire at the joint. This teeing-through of spares may mean a linesman having to assist the jointer in testing out spare wires from the distributing point, and possibly a test-room hand at the main frames for the same purpose. The joint would not then require to be touched until the time arrived to cut off the old cable, in the manner described in the illustration on the same page.

Mr. F. W. Best: Seeing that heat coils are referred to frequently in the course of the paper, it may be well to explain for the benefit of those members who are not telephone engineers, that a heat coil is simply a small fuse with a low melting-point placed in a holder at the termination of a telephone circuit. Although the use of tapes for withdrawing the heat coils is advocated throughout the paper, their tendency to become entangled in the heat-coil springs is a decided drawback to their use and I consider the employment of jumper wire for the purpose preferable. At Huddersfield, where an exchange transfer is pending, the change being unassociated with any extension of the underground system, the new exchange is separated by a short distance from the old local and Post Office trunk exchanges, which are to be closed. The lines on which the scheme of transfer is partly based provide for the system described under (*d*) Fig. 1, and in view of this I look forward with particular interest to the carrying out of the scheme.

Mr. H. A. Ratcliff: I may be labouring under a misapprehension, but from the remarks of a previous speaker I rather gathered that it was no disadvantage to a subscriber to have his telephone number changed.

I heartily disagree with that statement. In the case of many firms of repute their telephone numbers are almost as well known as their telegraphic addresses, or their trade marks; and further, they may have extensive stocks of stationery and publicity matter bearing their telephone numbers, in addition to such items as engravers' blocks, etc. That being the case it appears to me that a change of telephone number may be a source of considerable inconvenience and expense.

Mr. H. Escott: It may perhaps be of interest if I give some idea of the magnitude of the work entailed in transfers like that to the new Central Exchange, Manchester. This exchange contains the equipment of approximately 8,000 subscribers' lines and entailed the making and handling of about two million soldered connections, 25,000 strips of jacks each equipped for 20 lines, 5,000 operating cords and plugs, 5,000 miles of single-wire flameproof switchboard cable, 450 miles of lead-covered single-conductor cable, and 5,000 fuses varying from 1 to 5 amperes' capacity. The large quantity of switchboard cable is necessitated by the fact that each subscriber's line is available for connection at 50 points on the telephone switchboard. When the space occupied by a telephone switchboard is considered it will be realized how intricate and detailed telephone engineering becomes. I should perhaps mention that the temporary connections on the main frame referred to by the author were carried out in connection with the recent transfer of the Central Exchange and proved very satisfactory. Mr. Medlyn dealt with three successive visits to subscribers' offices. I might say that in the transfer previously referred to, one visit only was paid, and in connection with that visit the following tests were carried out:—Receiver polarity test, conductivity test, and insulation test. The results proved highly satisfactory. The same speaker, I think, also dealt with the question of rehearsals. I am in favour of these, that is to say, just going over the ground beforehand, especially for those officers who will be concerned with the manipulative portion of the transfer, such as disconnecting at the main frame and withdrawal of separators or clips from the line and cut-off relays. Such a rehearsal was carried out a week previous to the actual transfer of the new Central Exchange and, in my opinion, went far towards the success achieved. In conclusion, will the author please say what means should be adopted for preventing the heat coils—when withdrawn by tapes as described on page 392—from flying among the other protectors, and also what steps are taken for their collection.

Mr. H. A. Hincks: Dealing with Section IV ("preparatory line work"), I believe there is a standard distance between telephone poles, between the arms and between the insulators; a standard adopted in earlier days before central battery working came into vogue. It occurs to me that we have not altered these standards with our systems, and I should like the author to say if, in view of the fact that overhead wires in connection with central battery and automatic working carry permanent current, it is not advisable to consider whether these standards should be amended because of the liability of overhead wires to fugitive or intermittent faults due to wires coming into contact with each other, with trees or with buildings, etc., when they swing about. Where magneto systems exist these contacts do not much matter. Wires touch but generally nothing happens. With central battery systems, however, when wires touch there is often a tinkle of the subscriber's bell or a light on his calling lamp, and both the subscriber and the telephonist do much unnecessary work on that account. Dealing with the procedure for making tee connections, the author says (page 397, item *e*) "If after challenging, line proves to be disengaged." I am afraid lines are challenged more frequently than they might be before cutting into them. A subscriber recently told me that he had of late done more work for the telephone department in answering queries put by workmen as to what his telephone number was, than the department had done for him in the way of setting up connections. The author refers (item *f*) to the numbering of paper sleeves. A great deal of unnecessary disturbance to subscribers might be avoided by a full and proper use of these numbered sleeves. The transfer from magneto to central battery equipment has the unfortunate disadvantage of depriving some subscribers of facilities they have hitherto enjoyed. Under a magneto system a subscriber with one extension to his line has free talk between the main instrument and the extension without interfering with the exchange. When he is transferred to central battery working, we sometimes take away that privilege, or at least if the subscriber exercises it he jeopardizes his own service by calling the exchange unnecessarily, and it is up to the engineering branch to devise some cheap and effective method of getting over the difficulty. If we take away a portion of the facilities which he has had for years the change does not appeal to him as being so much an improvement as we make it out to be.

Mr. F. G. C. Baldwin (*in reply*): The paper is an attempt to deal in a general way with the various sections of work involved in carrying out a telephone exchange transfer and, owing to the broad field embraced, it has of course not been possible to deal exhaustively with each branch of the subject. Valuable and interesting information has been supplied in the discussion and the questions raised are so numerous and many of them so closely related that a collective reply will perhaps be preferable.

Line plant arrangements.—As suggested by Mr. Shea, a telephone line from the old exchange test-room to each jointer engaged in teeing the lines will certainly be useful, but the line to the new exchange is considered to be of greater importance.

The testing out and labelling of order wires, order wire junctions, and other circuits with no signalling facilities is not specifically treated in the paper and, as Mr. Shea states, they must be tested out and identified by the jointer working in co-operation with an officer located at the old exchange. It is preferable that this work be completed before the subscribers' lines are dealt with in each cable.

When testing out and labelling circuits in a joint, preparatory to teeing the lines into the new exchange,

it is perhaps immaterial whether cable pair or subscribers' numbers are utilized, provided that a uniform practice is maintained. One advantage of utilizing subscribers' numbers is that any desired subscriber's line may be identified without reference to a cable distribution schedule. It is essential that such schedules be kept up to date from the time of their preparation; new or ceased circuits may then be readily recognized.

It is interesting to note that the trouble experienced with the teed connections, mentioned by Mr. Shea, was remedied by the use of silk and cotton tail pieces, but the author has not found this or the similar use of tail pieces of vulcanized india-rubber insulated wire to be a satisfactory solution of the difficulty. To be effective the tail pieces must be used to terminate each of the three wires, forming one "leg" of a circuit, to be teed together. The number of wire joints and the space occupied is thereby greatly increased, and subsequent handling is still liable to disturb the paper insulation which remains. Although, as Mr. Upton points out, the effect of the waxing process is to render the insulating

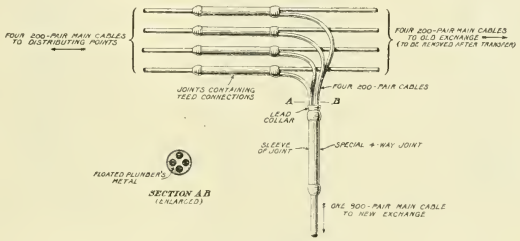

FOUR 200-PAIR MAIN CABLES TO DISTRIBUTING POINTS
FOUR 200-PAIR MAIN CABLES TO O.D EXCHANGE (TO BE REMOVED AFTER TRANSFER)
JOINTS CONTAINING TEED CONNECTIONS
FOUR 200-PAIR CABLES
A
B
LEAD COLLAR
SLEEVE OF JOINT
SPECIAL 4-WAY JOINT
FLOATED PLUMBER'S METAL
SECTION A B (ENLARGED)
ONE 900-PAIR MAIN CABLE TO NEW EXCHANGE

FIG. B.—Simple example of method of making plumbed joints containing teed connections (semi-diagrammatic).

paper more brittle and therefore more liable to fracture, the beeswax causes the paper to adhere to the wire and prevents it from untwisting. If the waxing process be thoroughly carried out, it is improbable that the normal handling will cause the paper to become separated from, and lay bare a length of the conductor, and so long as this does not happen mere fracture of the insulation is not likely to cause trouble.

Generally speaking, it should be possible hermetically to enclose each tee joint by means of a properly plumbed lead sheath, a method in which Mr. Upton is apparently in agreement with the author. The semi-diagrammatic line drawing herewith reproduced (Fig. B) illustrates a typical example of a satisfactory method of constructing tee joints under conditions met with at the present time, and Mr. Upton, like the author, appears to favour tee joints of this description.

The provision of spare pairs between each distributing point and both the old and new exchanges, in order to avoid disturbance to teed connections, is, of course, not always practicable, but where possible such a course is recommended. In some cases, spare pairs which might be used for this purpose may be unavoidably in temporary use for carrying working circuits for transfer purposes.

In reply to Mr. Hincks, experience shows that the standards used in magneto working, as regards clearance between one wire and another, and distance between pole and pole, are satisfactory for common battery working.

Mr. Wallace considers that the test for conductor resistance should not be left until the final visit of the instrument fitter. These tests are provided for in Fig. 20. Except through some unforeseen circumstance or fault, the conductor resistance is not likely to vary materially from that allowed when the line-plant scheme was prepared, and it is considered futile to make tests for conductor resistance until it is certain that the resistance will not be subject to variation, due to the line work which is proceeding, and until the permanent line circuit to the new exchange has been provided.

In most cases there is no difficulty in securing a much higher insulation resistance than the 100,000 ohms minimum recommended in the paper, and in a recent case an insulation varying from 0·2 to 17 megohms under the conditions named was obtained without difficulty. There is no objection to the higher minimum suggested by Mr. Upton being fixed, if desired, but there does not appear to be any justification for expenditure to be incurred in obtaining higher insulation than is necessary for satisfactory working.

Methods of effecting transfers.—The method of transferring each line independently is dismissed in one sentence as precluded by traffic considerations, and was only mentioned inasmuch as that method has been adopted in some cases in the past history of telephony.

The method of disconnecting the lines at the old exchange by the insertion of insulating wedges between the springs of the test jacks referred to by Mr. Wallace, possesses certain advantages over the withdrawal of heat coils, but unless the test jacks were situated on the line side of the protectors, which is unusual, it is not seen how the withdrawal and cleaning of carbon arresters could be avoided.

In reply to Mr. Escott, if it be desired to prevent heat coils from scattering upon withdrawal, the tape or cord used for withdrawal may be knotted round each coil so that the whole of the coils come away with the tape to which they are secured. It is doubtful, however, whether such laborious preparations are justified. When the heat coils have been withdrawn, working circuits end at the springs of the protectors and all other surrounding apparatus is thrown out of service (unless only a portion of the circuits on the exchange are being transferred) and the scattering of the heat coils is not likely to cause any material trouble. Screens of stout brown paper affixed to light wooden frames may be utilized to shield any surrounding apparatus which may remain operative after transfer.

Apart from the question of the protection of surrounding working plant, it is not deemed necessary to take any special precautions to prevent heat coils from scattering and for their collection. It is probable that the cost of such measures will amount to more than the small value of heat coils lost or damaged.

It is gathered from Mr. Upton's remarks that the separation of the old from the new plant by means of insulating plugs as shown in Fig. 5 of the paper has already been tried with satisfactory results. There is a disadvantage in using insulating strips instead of plugs, in that the testing of any particular line without disturbing the remainder of the circuits accommodated on the strip is rendered impracticable.

A description of the Peel-Conner type of relay and of the means adopted for separating the contacts of relays of this type was purposely omitted in order to curtail the length of the paper. The drawing exhibited in the form of a lantern slide, to which attention is drawn by Mr. Medlyn, is now included (Fig. C).

Transfer of junction circuits.—The importance of the work associated with the transfer of junction circuits to which attention is drawn by Mr. Stewart and Mr. Wallace has not been overlooked. It is fully recognized that in a large and important telephone system the amount of work involved in the preparation for and actual transfer of junction circuits is huge and its character complex. Some difficulty was experienced in preparing the paper in keeping it within reasonable limits, and this section of the subject was of too extensive a character to permit of it being adequately treated in a paper of this scope.

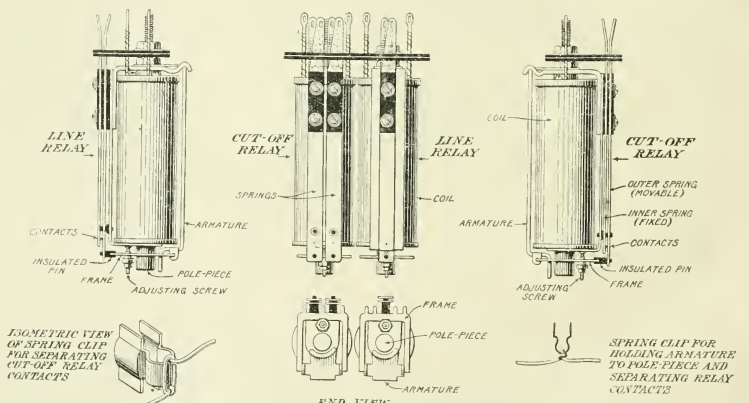


FIG. C.—Combined line and cut-off relay (Peel-Conner type).

Subscribers' apparatus.—Owing to the extensive character of this section of the subject, and to exigencies of space, it has not received in the paper the detailed attention which it deserves. The criticism and the valuable information supplied in discussion by Mr. Medlyn and other speakers are therefore all the more welcome.

It was not intended to convey the impression that the author was in favour of the retention, for an indefinite period, of modified magneto apparatus after transfer to common battery working, and he agrees with Mr. Medlyn that the full benefits of the change of system should be secured by entirely replacing all magneto by modern common battery apparatus as soon after the transfer as possible.

The fixing of new central battery apparatus alongside

the old with change-over switches has been adopted in several important changes from magneto to common battery automatic working, but the use of the change-over switch is likely to be abandoned in favour of the connection of the two instruments in parallel and the disconnection of the magneto bell of the old instrument.

Opinion appears to be divided as to the treatment which should be accorded single-extension installations fitted with extension switches. The method indicated in the paper, Fig. 15 (*b*), has been extensively used in connection with past transfers and, so far as is known, no trouble has been experienced. It is true that, after the transfer and until the apparatus is changed, a premature clearing signal will be given at the new common battery exchange while the main set is being used for communication with the extension end during a conversation via the main exchange, but it should be borne in mind that the operator at the common battery exchange will not clear the connection there unless both supervisory lamps are operated at the same time. The proportion of inward extension calls on these installations is very much less than is the case with private branch exchanges where holding coils are essential.

Where transfer from magneto to central battery working is contemplated in the near future, it is usual, in providing new subscribers' services, to fit a convertible type of telephone instrument. In such cases the fitting of a temporary condenser is obviated.

It is true that the practice of substituting old magneto by new common-battery private-branch-exchange switchboards in advance of the change-over has its disadvantages, but the objections appear less serious than those which accompany the modification of the magneto apparatus. The practice has been followed in several transfers of small dimensions (500 to 800 lines) with satisfactory results, but the author is not aware whether it has been carried out on a still more extensive scale.

In magneto-exchange areas where at a future date conversion to central battery working is contemplated, it is now customary to fit common battery apparatus throughout for private branch exchange installations and this is done with success. The treatment which is necessary must vary with the class of switchboard, of which there are several types, and the subject can here only be briefly dealt with in general terms.

Where power can be supplied as a permanency by power line from the new exchange, the course advocated in the paper is very much less costly than that of modifying existing apparatus and replacing it after transfer. The same also applies in cases where primary cells are to be permanently used for supply of power; where the circumstances are such that primary cells must be used as a temporary expedient, until power can be supplied shortly after transfer, the difference in cost of the two alternatives is negligible. Night service can readily be provided for. The number of extensions for which night-service facilities are required is always small in comparison with the total number of extensions. The provision of a magneto at the extension end will provide means for calling and clearing to the main exchange when plugged through, or the existing telephone instrument may be modified to work on the new private branch exchange and changed after transfer according to circumstances. The selected extension line can readily be joined up to the relative exchange line by means of a special cord or key supplied for the purpose and recovered after transfer. One of the disadvantages of the method is that to which Mr. Medlyn draws attention, viz. the clearing. During the period intervening between the installation of the new common battery apparatus and the transfer, it is necessary that the private branch exchange operator should transmit a magneto clearing signal to the main exchange on conclusion of each conversation with a subscriber on the main system. There is, of course, a possibility that, even with the best possible management, the observance of this rule may not be strictly followed, but no trouble has been experienced from this cause in the cases in which the author has been concerned. Further, it should be remembered that in the magneto system, a clear is given by each of the two subscribers concerned on conclusion of conversation, and the difficulty mentioned by Mr. Medlyn is only likely to arise when two private branch exchanges engaged in conversation via the main exchange both fail to give the required clearing signal.

Transfers to automatic working.—These have not been specifically dealt with in the paper, but the actual methods of transfer described may equally well be applied to automatic as well as manual working. Testing of the subscribers' circuits after transfer to an automatic exchange is one matter which requires to be specially catered for.

Tests preparatory to transfer.—Mr. Medlyn questions the necessity for making all the three tests of each circuit before the transfer (*a*) at the fitter's initial visit, (*b*) at the fitter's final visit, and (*c*) finally before transfer. In a large transfer it will barely be possible to avoid two visits by the fitter to the subscriber's premises, one to prepare the apparatus for transfer, which work must usually commence long before the new exchange is ready and even before the subscriber's line is connected to it, and another in order to co-operate in the working tests to the new exchange. In a small transfer it might not be difficult to arrange for the fitter's work and the working tests to be combined in one visit, and in such a case the costs will be proportionately small. The final tests recommended in the paper are for the purpose of ensuring at the latest possible moment before the transfer that each subscriber's circuit is in a satisfactory condition for transfer. In a large transfer the work to be done on the subscribers' lines and installations is considerable and may occupy a prolonged period, during which cessations, new lines, removals, etc., are proceeding, and even with the most careful organization there is some risk of confusion or error; the third test is therefore considered to be an essential and inexpensive safeguard.

Programme instructions.—The issue of a schedule of detailed instructions to each officer taking part in the transfer, referred to by Mr. Medlyn, is provided for in Section XII of the paper, see item "*k*" of the programme headings recommended.

Control of transfer.—Mr. Wallace is right when he says that the control of a transfer operation must be co-operative in the sense that the chief officers of the engineering and traffic departments must act in close co-operation. The reference in the paper to the control being situated at the test desk refers to the officer in immediate control of the engineering operations.

Change of number.—With respect to Mr. Ratcliff's remarks regarding the disadvantages to the subscriber of changing his telephone number, Mr. Staite has shown that such changes are not made without good reason and unless absolutely necessary. Engineering considerations sometimes demand change of number, and a telephone exchange transfer is but one example of an engineering operation where a change of number is sometimes unavoidable.

Co-operation.—With regard to Mr. Staite's plea for co-operation, the author considers that the success which has attended transfers already carried out is largely indicative of the satisfactory co-operation which is readily secured.

Battery.—Mr. McKinnon raises a question which can scarcely be regarded as arising out of the paper. The quotations he makes from the paper should not be separated from their context. He apparently concludes that the battery is utilized in connection with the whole of the tests to which he refers. This is not the case. The battery for a new exchange is generally supplied and fitted by the battery contractor to the order of the firm contracting for the complete exchange equipment, and the date of delivery is a matter of arrangement between those parties. The maintenance of the battery prior to acceptance of the equipment is also in the hands of the contractor. Mr. McKinnon's reference to battery overhaul is somewhat cryptic, but so far as the author is aware, no great difficulty has been experienced in carrying out battery overhauls in conformity with the stipulation to which he refers, a requirement which, incidentally, is essential to safeguard the interests of the telephone public.

The interesting information supplied by so many speakers respecting the large and involved transfers executed in the Manchester neighbourhood is an indication of the magnitude and complexity of the work entailed in a transfer and of the careful organization which is essential to success.

Newcastle Local Section, 11 February, 1918.

Mr. J. R. M. Elliott: The author has referred to three different methods in which a transfer may be effected, but I think there can be no question that the most efficient and economical one is that of transferring the whole of the lines at one operation. It would be interesting, however, to learn of any cases where a transfer had been effected by changing over each exchange line independently. In designing the re-arrangement of line plant, it is of the greatest importance, from the point of view of both efficiency and economy, to weigh carefully the alternatives which the author has outlined on page 391. No hard and fast line should be drawn, as each case should be decided on the local conditions prevailing; but the advantages attending the diversion of all lines to the new exchange and extending them temporarily to the old exchange are so considerable that this method may often be justified even at slightly increased cost. In effecting the actual transfer operation at the time appointed for the change-over, the author has shown the method usually adopted at the old exchange for ejecting the heat coils from their clips. This may be a rapid device for carrying out the operation, but it seems to me a barbarous way of treating apparatus, as the coils are scattered over the floor of the apparatus room. A better method would perhaps be to encircle each coil with a clip suitably designed to enable a string to be passed through the whole bank, so that when ejected each would be held in its respective clip on the string. This raises the question whether momentary transfers are really necessary. Personally, I do not think they are. It perhaps sounds well to say that the change-over was practically instantaneous, but to obtain this result the risk of introducing confusion is so great that I prefer each of the various operations to be assigned a definite time for its accomplishment, and so spread the total period over an interval of, say, five minutes, an interval which, I am sure, would not unduly inconvenience subscribers. Perhaps the most convenient time for conducting a change-over is, say, 2 p.m. on a Saturday afternoon, when the traffic falls off. This enables the jointers to deal with a large number of the teed connections and permits much clearing-up to be done before the following Monday morning. At exchanges where the latest form of protector having a double spring is in use, as explained by the author, it will be a decided advantage to use the wooden insulating plugs at the protector rather than the fibre separators at the cut-off relays. If the plugs are not easily withdrawn owing to their roughened surface, a very slight smearing of the flat faces with a vaseline rag will ease the friction and cause them to respond readily. The greatest care should, however, be taken to use as little vaseline as possible. The author has explained the desirability of having relatively high insulation of the line plant for central battery working. This, of course, is applicable also to automatic exchanges and cannot be too highly emphasized. From my own experience of a transfer conducted before new cable had been substituted for the open lines of low insulation, I would strongly recommend postponement of the transfer rather than to proceed with low insulation of the line plant. On page 403 the author appears to regard 100,000 ohms as a safe insulation value, but many of the circuits are largely composed of open wire, which is of course affected by the condition of the weather. I have known instances of a route of wires to fall in the early morning to as low as 40,000 ohms per mile although working well, and to rise to 200,000 ohms by 10 a.m., increasing to 1 megohm by noon. It would, therefore, appear to be a matter largely for the exercise

of discretion of the officer responsible as to whether, in the case of open lines, the insulation is satisfactory. If a minimum is to be fixed, a much higher value than 100,000 ohms should be adopted. The question of supplying workmen with suitable diagrams for their guidance, referred to on page 397, is one which does not always receive the attention that it deserves. The cost of proper drawings and prints has of course to be taken into account, but expense incurred in this direction will be amply justified by increased output due to their use. It is perhaps less trouble for supervising officers to issue verbal instructions to their men, but in my opinion these should be limited only to simple cases. The jointing of light-gauge cables (page 398) is an operation which requires the greatest care on the part of the jointer. The precaution which the author suggests, of treating the wires with hot beeswax and binding them with a thread, may appear to be laborious, but the results justify the procedure, and in consequence of the greater freedom with which the wires can be handled after being waxed it is perhaps a moot point whether the process adds to the cost of the work, especially where large cables are concerned. Vulcanized rubber-insulated wire has been tried for making the connections, but this has proved to be unsatisfactory in consequence of the joint becoming too bulky. In addition, the comparatively high price of the rubber wire increases the cost, and the jointing is perhaps no easier than with paper to paper. In effecting the change-over from magneto to central battery at subscribers' ends, the author has explained three alternative methods of carrying out the work, but I think there can be no question that, generally speaking, in the cases of simple sets it is better temporarily to modify the existing apparatus and to substitute after the transfer the new set. This is a cheaper method, avoids disturbance of the wiring of the new apparatus, and reduces the amount of work to be done by the fitting staff in preparing for the transfer, after which the substitution of the new sets can be proceeded with as circumstances permit. The author has referred to a time-table on page 409. In the transfer of an exchange, too much importance cannot be attached to the necessity for carrying the work through to completion quickly, from the time the plans and estimates are prepared, in view of the circuit alterations which are constantly taking place in connection with removals, cessations and new subscribers, which often involve departure from the original estimate. Although each of these details may be small in itself, yet taken as a whole they may considerably affect the total estimated cost of the work, and if careful records are not kept the resulting excesses may be difficult to explain. Hitherto it has been the practice to subordinate transfer work to other of more pressing character, with the result that in many cases the work of transferring an exchange has been allowed to be spread over a period of two or even three years, mainly because there has been no time-table to work to, and in these cases it has been impossible to follow precisely the original estimate in consequence of the changes in plant which have meanwhile occurred. A time-table would to a large extent avoid prolonged transfers of this kind. Material assistance will be afforded the engineer in co-ordinating the various

FAULT DISTRIBUTION RETURN.

EXCHANGE..... PERIOD ENDED.....

Day of Month	Number of Faults																																				Duration of Faults	
	Line				Subscriber's Apparatus														Exchange												Grand Total								Faults Cleared within	
	Open Wires	Leads	Cables	Found O.K.	Cleared	Reported	Carried Over	Internal Wires and Protectors	Receivers and Induction Coils	Transmitters	Cords	Bells	Generators	Switchboards	Switches	Batteries	Found O.K.	Cleared	Reported	Carried Over	M.D.F.	I.D.F.	Relays	Exchange Fuses	Cord Circuits	Multiple Equipment	Local Equipment	Junction Equipment	Found O.K.	Cleared	Reported	Carried Over	T.O.K.	Cleared	Reported	Carried Over	3 Hours	6 Hours	18 Hours	24 Hours	48 Hours	Over 48 Hours

FIG. D.

sections of the work, but unfortunately circumstances often arise over which he has no control, such as delays by manufacturers in providing ducts, cables, and other material, by contractors in laying ducts or pipes, and by public bodies in granting wayleave consents. These have all to be taken into consideration, but nevertheless the suggestion is a good one and to be commended. For some reason or other, the author has not referred to the important question of faults during the period immediately succeeding the transfer. That is a period full of anxiety to the engineer and, generally speaking, the performance of the transfer work is reflected in the number of faults to be dealt with. Weaknesses not anticipated may make themselves felt, and it is necessary that the engineer should be in a position to know readily in what part of the system the trouble is being occasioned. A section fault schedule (see Fig. D herewith) enables this information to be tabulated from day to day. It is desirable that some standard should be worked to with regard to the maximum number of faults which should be expected to occur in the transfer of an exchange; 2 per cent does not seem a big number when an exchange of 500 subscribers is to be dealt with, but 2 per cent in the case of an exchange with 5,000 subscribers is 100, a large number to cope with. From my own experience, I should be inclined to lay down 0·3 per cent as a standard to be worked to, and in a well-organized transfer this number should not be exceeded.

Mr. H. Kitchen: The question of storage has not been mentioned by the author, and I think it will be agreed that, in starting a work of an extensive order, storage should be arranged for and premises taken for the accommodation of material and apparatus. A qualified storesman familiar with the various kinds of telephone apparatus and materials should also be engaged; the work would thus be greatly facilitated. From the time an exchange transfer has been decided upon, I think canvassing should not be carried on, and new subscribers' lines should not be fixed or, at any rate, should be kept to a minimum. In the latter case convertible apparatus should be installed. With regard to the use of strips of protectors for cross-connecting, as these are fitted with heat coils several disadvantages are introduced. Potential faults at the carbons and in the heat coils create a weakness in the system. Another point is that soldering is likely to be difficult, and altogether I do not think they are better than the cut-in jacks supplied for the purpose. I think the cut-in jack such as we use is more readily handled, and the connections are seen and can be inspected without any trouble; also this method would be cheaper. The standard jack in use is somewhat clumsy, and not easy to operate quickly. Fig. E illustrates a new jack which remedies the defects mentioned. On page 398 the author refers to the weakness of paper cables when opened for tee connections, etc. May I suggest that the condition of the cable may be further safeguarded by making the exposed joint with wax; otherwise by replacing the lead sleeve with a coating of wax applied and worked in much the same way as solder for a plumber's wipe. This could be removed quickly and readily by applying hot wax. Fig. 12 is somewhat misleading. If a single grooved insulator is used it is evident that when the tee connection is severed the old and new line conductors are still in contact. On page 400, a highly controversial point is raised in connection with the displacement of apparatus connected to private branch switchboards. To avoid trouble in transmitting clearing signals to the old exchange, and to provide night working facilities, the best plan appears to be to fit convertible apparatus, that is to say, sets which will work to both magneto and central battery exchanges. The generators and speaking batteries will of course be recovered after the transfer has been made. The

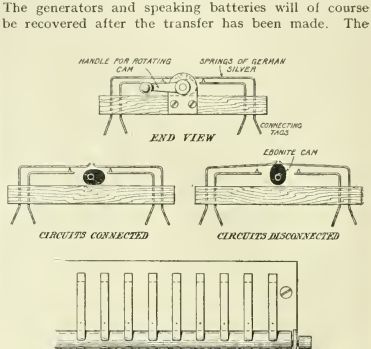


FIG. E.—Proposed cut-in jacks for exchange transfers.

author refers on page 405 to the disconnection of heat coils, and I should like to supplement his remarks. In an actual transfer work the coils were taken out for testing and it was found impossible to get them back again as the spindles varied considerably in length, and certain coils would only fit particular springs. A special tester was made which not only gauged the coils, but proved the continuity of the conductor. Rejected heat coils were subsequently treated and reissued. The insulation resistance of a line is also somewhat controversial, and I am afraid I must differ from Mr. Elliott. If a standard is not fixed and it is left to the discretion of the man on the spot, no results whatever are obtained and recorded. I think a minimum insulation of 200,000 ohms per mile should be obtained, and this under the worst possible weather conditions. In connection with post-transfer work, schedules for fitters' work and the recording of new apparatus have been found invaluable and specimen schedules are reproduced herewith.

.....EXCHANGE SUBSCRIBERS' APPARATUS.

Instructions for Changing to C.B. Working.

1. All apparatus will be stored in the shop at .....

2. This stock will be in charge of Foreman Fitter ..... who will have all new apparatus cleaned, tested, classified, and sorted, and suitable instruction card supplied.

3. Storeman ..... will assist with the stock and pack and despatch all recovered apparatus.

4. Schedules of subscribers (as per specimen attached) will be prepared by the Foreman Fitter, under the instructions of Inspector ..... for each fitter daily.

5. When the day's work is finished, the fitter will return the schedule correctly filled up to the Foreman Fitter. The recovered apparatus will be checked by the storesman after the schedule has been approved.

6. The storesman will initial the sheet as an acknowledgment of receipt of the recovered items and return to the Foreman Fitter.

7. The Foreman Fitter will enter up his Apparatus Register from the completed schedules daily.

8. A summary of the sets changed will also be kept by the Foreman Fitter for checking progress.

9. Fitters' mates will be responsible for the delivery and collection of new and old sets. The boy will prepare for the fitter by having the new apparatus ready for fitting at the subscriber's premises. After delivering the new set he will call for the last set changed. After handing this into stock he will take a new set to the next subscriber on the schedule.

10. Recovered apparatus will be despatched in regular consignments and not allowed to accumulate.

11. The fitter will call up the Foreman Fitter after completing and testing each instrument fitted and report progress. Difficulties will also be reported to the Foreman.

12. A suitable supply of packing cases and materials will be held and these will be stored in a dry place.

.....

.....EXCHANGE TRANSFER.

Changing Subscribers' Apparatus.

Subs. No.	Name	Address	Apparatus		Despatched		Works examined and approved by	Remarks
			Fitted	Recovered	On	By		
							(Signature)	

Name of fitter.....
Date.....
Locality of work.....

Mr. G. Bailey: With regard to Fig. 8, illustrating a method for transfer of junction circuits, I think the original practice has been to pass only private wires, order wires, and through junctions through the test break-jacks. Will the author kindly say if the system shown is becoming uniform in its application? Where no test box facilities exist, as in the case of modern central battery exchanges, the proposal to pass all junctions through the test break-jacks is a good one, and if the practice is becoming general it is a step in the right direction to facilitate testing both the outside line plant and the internal equipment. With reference to the insertion of holding coils, it is stated that to guard against premature clears being given at the exchange from private branch exchanges it "may" be necessary to provide "holding coils." Should this not read it "will" be necessary, as these coils are thought to be actually necessary in such cases. The author has not touched upon the work at private branch exchanges. Some of these systems present real difficulties in connection with transfers, and perhaps the author might have some remarks to make on this part of a transfer. I notice that the Peel-Conner type of relay is not referred to in the paper although the author has shown a slide of this type of relay.

Mr. E. E. Gregory: With regard to item 6 on page 392 in connection with the transfer of line plant, I do not quite follow the advantage to be gained at the time of transfer, where reference is made to the "possible renewal of old plant," and I would ask to what does this particularly refer. With reference to the transfer of junction circuits (page 396), perhaps the author would say whether any trouble has occurred or is likely to occur when the trunks and junctions are transferred, as these are complicated circuits with special facilities and diverse methods of working.

Mr. A. C. Hovey: My remarks are made from the standpoint of that important section of the community—the telephone subscribers. I think if subscribers realized the work involved in such an undertaking as has been described by the author, they would have much more respect for the telephone authorities than they now possess. The Schedule (Fig. D) shown by Mr. Elliott includes a large number of columns for faults, indicating the many complicated problems present, and the comprehensive administrative knowledge which must be applied in their successful solution. A point of great importance in the transfer of exchanges is the changing of subscribers' telephone numbers in an apparently arbitrary manner. The public dislikes unreasoning bureaucracy; and it would be much better if telephone numbers were unaltered, as they are used for telegraphic addresses and become almost like trade-marks. Serious inconvenience is caused for a long period when a number is changed. I think the planning of the technical and administrative work described is an exposition of efficient forethought and careful control.

Mr. G. F. Bellwood (*communicated*): The arrangements to be made for a telephone transfer are always of a complicated nature and require much thought and consideration for the operations to be effected successfully, and it is undoubtedly good practice to

carry out as much as possible, if not all, of the permanent work before the actual transfer in order that the new service may give satisfaction immediately it is installed. A certain amount of interruption in the working of the subscribers' lines is almost inevitable, and it is desirable that subscribers should not be given cause for mistrust or be critical of a new system by being subject to unnecessary interruptions of the service. The subscriber will better appreciate the benefits derived from the introduction of a more modern system if from the outset it gives better results than the old, and knowing that a change of system is contemplated will be disposed to make allowances which he will be unwilling to concede after the change has taken place. Bearing these facts in mind, I am of the opinion that it is incumbent upon the engineer to see that the service is as perfect as possible immediately after the transfer, and this cannot be done where "limited line plant" is used for making the transfer; therefore, the complicated operations shown in (*d*), Fig. 1, should only be resorted to in cases of absolute necessity, and I consider that as a general rule methods (*a*), (*b*), or (*c*) should be adopted. The first two methods, (*a*) and (*b*) in Fig. 1, are fairly simple and also economical, but in the case of (*c*) the question of the cost of the additional cable plant does undoubtedly enter into account, and this point requires careful consideration. If the underground cable system feeding the old exchange is of comparatively recent date it will generally be found that provision has been made for several years' anticipated growth of the telephone system, consequently there will be a large number of spare conductors which require to be connected to the new exchange in any case, and which can as a temporary measure be utilized in making part of the provision necessary in stage 2 of method (*c*), the balance being made up by provision of cable plant sufficient to take the remaining circuits. This cable plant might be left in situ after the transfer and become a charge to capital, and it is a question whether it is more economical to incur annual charges on the capital expenditure, spread out over the anticipated number of years before the cable would be revenue-earning, or whether it is desirable to incur the revenue charges necessary to effect the limited transfer shown in Fig. 7. It may be considered desirable to withdraw the additional cable after the transfer, in which case both charges are proper to revenue and a comparison of the estimated costs can readily be made. Take a case where the line plant to the old exchange is nearly exhausted and spare plant to the distribution poles is not available. Here it will be necessary not only to provide cable of sufficient size to carry the whole of the lines concentrated on the old exchange to the new one, but also a duplicate cable to connect the lines back from the new to the old exchange until after the transfer. This duplicate cable may, however, be exceedingly useful in providing conductors to supplement the nearly exhausted system, and this could be readily ascertained by means of a survey, which would be necessary in any case in order to ascertain the estimated development over a certain number of years. The figures so obtained would enable the annual changes on the capital cost to be determined, and it might be found economical to provide the cable quite independently of its value during the transfer period. If the estimated annual charges involved in providing the additional cable in either case are not abormally above the revenue charges, and having regard to the improvement to the telephone service which would undoubtedly ensue after the transfer, then method (*c*), page 391, should be adopted in its entirety. From a consideration of Figs. 6 and 7 it will be seen that the disadvantages following the adoption of the system embraced in the latter figure, which are enumerated by the author on page 392, are real ones, and in addition the connection of new telephone services and the cessation of old ones increase the difficulty. In regard to paragraph (*b*) in the first column on page 404, dealing with preparatory work at the new exchange, this procedure will enable the test clerk at the new exchange to test out the shunted line as shown in Fig. 2; but in Fig. 6 the withdrawal of the heat coils should be done at the new exchange in a similar manner to the actual transfer, and not at the old exchange. Again, in Fig. 7, the withdrawal of the heat coils of subscriber No. 1 at the old exchange is not necessary, the withdrawal of the temporary heat coils at the new exchange enabling the test clerk there to test the line. To test out subscriber No. 2 at the new exchange involves three operations at the old exchange and one at the new exchange, and also the stoppage of subscriber No. 1. This emphasizes one of the difficulties encountered in adopting the "limited line plant between exchanges" scheme already dealt with. In certain cases the temporary heat coils at the new exchange are dispensed with by the use of ordinary spring jacks known as change-over strips, and whilst this method cuts out the resistance of the temporary heat coils before the transfer, the actual transfer is not so readily accomplished, especially where the tape method of withdrawing heat coils is in use. Next, in regard to internal wiring (page 401, item *d*), this item should, I think, also include: (*a*) any change of protection necessary, (*b*) replacement of old-type heat coils for one uniform central battery type, where not already installed, (*c*) the replacement of all paraffined types of wiring, good or bad. It may be mentioned that the old form of heat coil acts with 250 milliamperes, whilst the new central battery type takes 500 milliamperes, and the resistance of the former is also a great deal in excess of the newer central battery type; hence, for these reasons, all old-type heat coils should be replaced. Finally, in regard to Fig. 17, it is suggested that this form would be more complete if columns were added to provide for:— (*a*) Defective wiring, (*b*) protection, (*c*) condition of earth connection (the latter very often omitted altogether, or an unsuitable earth connection made), (*d*) condition and class of internal wiring. It is understood that where the opportunity is taken to change the system from, say, magneto to central battery at the same time that the transfer is carried out, it is usual to re-wire certain of the subscribers' offices, either because the leading-in point is altered or because of defective wiring, but it is considered that the addition of the items enumerated would systematically bring all stations under review.

Mr. J. S. Terras (*communicated*) : In the selection of a method for carrying out any portion of the work of a telephone-exchange transfer, I think it is impossible to over-emphasize the importance of interfering with working circuits as little as possible, or preferably not at all, after the actual transfer has taken place. This applies especially in those cases where a change of system is concerned ; the new system, in fairness to itself, should have as clean a start as possible. Any failure to let it have such a start will be liable to react prejudicially on the service, because it will create difficulties for the traffic staff and will depreciate the reputation of the new system, of however good a type it may be, with the telephone-using public. The public will generally put up with some shortcomings or inconvenience in connection with the service during the preparatory stage without complaint, but if such conditions continue after the transfer, irritation is likely to be caused. I am therefore generally in agreement with what the author says as to the relative merits of the four methods of dealing with the line plant shown in Fig. 1. The ideal method is of course (*c*), and its advantages are so pronounced that the provision of the extra cable capacity—that is, in excess of the provision for future development which purely economic considerations make desirable—which its adoption may entail, will in my opinion be justified up to a certain point. Method (*d*) is the most economical in the use of line plant, but it has the serious drawbacks which the author enumerates. In connection with Section IV of the paper, I should like to suggest the desirability, in connection with the insulation tests, of having a voltage equal to the voltage of the new system impressed on the subscribers' lines for an extended period—say not less than 48 hours in each case—in order that weak points in the insulation may be broken down. Such a test may reveal weaknesses which the momentary test with a "Megger" or from the test-desk will not show up. The subscribers' lines can be so tested in groups of convenient size. With regard to Section V, if the transfer is one which involves a change in the type of telephone, I see no reason why the new instruments and private branch exchange switchboards should not be fitted in their permanent positions in advance of the transfer. In the case of simple installations the old telephones would be left in bridge with the new instruments until the transfer had been carried out. The problem of requiring the subscriber to find space for both the old and new sets during the preparatory period might be expected to present difficulties, but my experience has been that this difficulty is really negligible in the case of transfers to automatic working, where of course the fitting of the new instrument with its dial switch in advance of the transfer is essential, and I see no reason to apprehend any difficulty where ordinary central battery instruments are concerned. Instead of providing change-over switches, I prefer the fitting of temporary condensers in the bell circuits of all the old instruments, as it is impossible to rely on all the switches being thrown at the time of transfer, owing either to forgetfulness on the part of subscribers or to premises being closed. It is not considered that this method need be more expensive than method (*b*) described in the paper if the work be carefully laid out. With method (*b*) the fitter must in any case visit the premises twice, and the same number of visits would suffice for the alternative method. For installations with switchboards, method (*c*) described in the paper is, I think, generally the best. Arrangements on these lines are supported by the same argument which applies in the case of the line plant, viz. that it is undesirable to disturb any of the working plant for the purpose of making changes after the transfer has taken place.

Mr. F. G. C. Baldwin (*in reply*) : For the reasons given in replying to the discussion in London and Manchester, it is proposed to adopt a similar course to that followed there and to reply collectively.

Line plant arrangements.—Existing line-plant conditions constitute the governing factor in deciding the method or combination of methods to be adopted for transfer, and the author agrees with Mr. Elliott that it is not possible to regard any one method as standard. It is frequently necessary to embody two or more methods in one scheme.

The comments by Mr. Bellwood and Mr. Terras emphasize the objections to the method of transfer illustrated in Fig. 1 (*d*) and tend to show that in some cases the advantages of that illustrated in Fig. 1 (*c*) can be secured at little, if any, increase in cost.

Mr. Gregory asks for some explanation of the last quoted advantage of the method of transfer described, in which all lines are diverted through the new exchange prior to transfer. There are several conditions under which this advantage may be secured, and to cite one simple case will perhaps suffice. Where the lines are teed into the new exchange for transfer, if the insulation of the section of line between the old exchange and the teeing point (which must be left as a tee upon the circuit after transfer has been effected) is not sufficiently good for common battery working, it will be necessary to incur expenditure in suitably raising the insulation, probably by renewal of that portion of the plant affected. Such costs will be entirely avoided by adoption of the method of transfer in question.

Some special treatment of paper-insulated wires at underground teeing points is considered essential, for the reasons stated in the paper, and although the process of waxing recommended causes the insulation to break with less provocation than if untreated, it also has the beneficial effect of preventing the paper from untwisting and causes it to adhere to the wire. Therefore, even with excessive handling, it is improbable that the conductor will become seriously exposed, mere fractures of the insulation being unimportant so long as the insulation does not strip from the wire. Beeswax is decidedly preferable to paraffin wax for this purpose. The use of vulcanized india-rubber referred to by Mr. Elliott, or of silk and cotton insulated tail pieces for forming tee connections, is not in the author's opinion advantageous for the following reasons :—(*a*) the bulk of the conductors and the space occupied is greatly increased. (*b*) The number of wire joints is increased. (*c*) Insulation of silk and cotton insulated wires is difficult to maintain under prevailing conditions. (*d*) Connections must still be made to the paper-insulated

wires, and unless these are formed in plumbed joints entirely separate from those containing the tee connections they will still be subject to interference. (e) The costs are high.

The solid waxed joint suggested by Mr. Kitchen would be impracticable, as it would be impossible satisfactorily to separate the wires for subsequent jointing operations. As Mr. Kitchen points out, the cutting away of the tee piece as indicated in Fig. 12 does not actually sever the electrical connection, which must be completed by removal of the discarded portion of the circuit. This point is covered under "Removal of Tees" in Section XI of the paper. Simultaneous severance of the electrical connection when the tee is cut away can be arranged by interchanging the wires "to old exchange" and "to new exchange" shown in Fig. 13; but if this be done, the permanent wires will finally be in the same groove of the insulator.

Methods of effecting transfers.—The transfer of each line independently is a process which need not be considered at the present time. In the past history of telephony, this method has, however, been adopted in numerous instances, and is therefore referred to in the paper. Although it is desirable that the actual transfer operation should be performed in the shortest possible space of time in order that the telephone service may be interrupted as little as possible, it is not considered desirable that money should be spent and risks taken merely for the purpose of creating a record. As Mr. Elliott points out, undue haste may lead to confusion.

The protectors utilized as shown in Figs. 6 and 7 as a temporary measure are considered preferable to the "cut in" jack because of the greater rapidity with which lines may be disconnected by withdrawing heat coils rather than by inserting insulating plugs. The jack suggested by Mr. Kitchen would no doubt possess advantages, but the cost has necessarily to be taken into account, and the increased space which would apparently be occupied is also an important consideration.

Mr. Elliott's remarks regarding the scattering of heat coils are appreciated. Various measures for the prevention of scattering have been tried, but no practical advantage has so far been secured; considered apart from the production of faults by lodgment of liberated heat coils in parts of operative apparatus, the cost of any such measures should of course not exceed that of replacing heat coils lost or destroyed, usually a very small matter. A suitably designed clip as suggested by Mr. Elliott would certainly possess advantages, but there are difficulties in designing a satisfactory clip which, so far, have not been surmounted; one of these is that the clip must not be metallic as it would be liable to cause faults.

In reply to Mr. Bailey's question, so far as the author is aware it is not likely to become uniform practice to pass all junction circuits through break-jacks at the exchange, the expense not being justified. Where such jacks exist they may conveniently be made use of as described in the paper, otherwise temporary jacks can be easily provided if desired and the cost is not prohibitive.

As Mr. Gregory points out, methods of junction working are diverse and the circuits sometimes complicated; consequently extreme care is necessary in dealing with the transfer of junctions. Owing to the extensive character of this section of the subject and to limit the paper to reasonable length, it has not been possible to deal with it as exhaustively as the author would have preferred.

The method of transfer of junction circuits illustrated in Fig. 8 is both simple and expeditious and no trouble is likely to arise by the adoption of this method, provided of course that the junction apparatus at the home and distant exchanges has been suitably arranged for working, and that the requisite provision has been made for transfer to the previously fitted new equipment, if any, at the distant end.

Particulars of the Peel-Conner type of cut-off relay with means for separating its contacts have been supplied in the reply to the discussion in Manchester (see page 424).

Mr. Bellwood has pointed out that the testing procedure at the new exchange described on page 404 does not apply when the method of transfer illustrated in Fig. 7 is adopted, and he shows in what manner testing is rendered more complicated and difficult when that method is utilized. In this connection it should perhaps be mentioned that, although more than one method of transfer is dealt with in Sections II and III, it has not been possible to include particulars of testing, jointing, and other procedure peculiar to each method of transfer. In describing procedure included elsewhere in the paper, it has been assumed that the simpler method shown in Fig. 2, which is perhaps most frequently utilized, has been adopted to the exclusion of other methods.

Preparatory work at subscribers' stations.—Several speakers, including Mr. Terras, have referred in various terms to the interesting subject of "preparatory work at subscribers' stations." Owing to the exigencies of space this section of the subject has not received in the paper the full consideration it deserves, and the various comments made in discussion are therefore particularly acceptable.

To avoid fitting a change-over switch Mr. Terras suggests that the new telephone be fitted in bridge with the existing set, and that the latter be recovered after transfer. Where space is available and the subscriber has no objection, I think such a method is satisfactory except that the labour costs are likely to be rather high. If the bell of the old instrument be disconnected and the bell of the new one is utilized for calling the subscriber, the fitting of a condenser is unnecessary, a rather important consideration. For the sake of uniformity, it is desirable that as far as possible only one method of treatment of subscribers' apparatus should be followed in one transfer.

The consensus of opinion appears to be that the treatment of private branch exchanges advocated by the author is generally the best. The subject is so large that it is quite impossible to deal with it exhaustively in replying to the discussion, as has been suggested by Mr. Bailey. The subject has, however, received further attention in the discussion at Manchester (see page 424) to which reference may be made.

In order to overcome the difficulty of providing night working facilities and of transmitting clearing signals to the old exchange in connection with private branch exchange installations, Mr. Kitchen suggests that the best plan is to fit convertible apparatus. If all extension lines accommodated on switchboards were treated in this way—and this course would be necessary if it were required to obviate the private branch exchange operator giving a magneto clearing signal after each call—the cost would be prohibitive, particularly in the cases of large private branch exchanges.

Mr. Bellwood correctly draws attention to three items, not mentioned in the paper, needing attention at subscribers' stations.

In reply to Mr. Bailey's question, the author cannot point to any case of a private branch exchange where, under the conditions mentioned, the holding coils referred to in Section V of the paper should not be provided.

General.—Mr. Elliott raises the highly interesting and controversial point of the allowable insulation for common battery working, and he very clearly shows how wide are the limits of insulation of a line with open wire in its composition. The changeable weather conditions experienced in this country are one of the difficulties with which a testing officer has always to contend. Discretion must of course be used in passing, for transfer, lines which have been tested for insulation. Although Mr. Elliott does not quote any figure, it is gathered that he prefers to work with a much higher minimum than that suggested in the paper. So long as expenditure is not incurred in raising the insulation to a figure higher than is necessary for satisfactory working, the author sees no objection, but it is interesting to note that numerous transfers from magneto to central battery working have been carried out in the past, with entirely satisfactory results, where a minimum insulation even less than that recommended in the paper has been imposed. The method of measurement described in the paper is convenient. Inasmuch as the whole of the circuit, and therefore apparatus and internal wiring as well as line, is included in this test, a figure expressed in ohms per mile, as mentioned by Mr. Kitchen, is unsuitable.

The form suggested in the paper in Fig. 17 is primarily intended for the use of the test clerk in recording the results of, and as a check upon, the tests made by him, and the author considers it undesirable that the use of the form should be extended as suggested by Mr. Bellwood so as to provide for defective wiring, protection, etc., these items being matters which are best dealt with by the officers directly superintending the work of the fitting staff.

Mr. Terras suggests the desirability of applying to the subscribers' lines for an extended period before the transfer a voltage equal to that of the new system. Such a test would be advantageous in that it might reveal weak points of insulation not detected by the usual momentary tests. Special arrangements would, however, be necessary to permit of the test being made without interference to the service, and it is perhaps questionable whether the expense incurred would be justified by the results obtained.

During the period immediately following the transfer, it is of course desirable that the working of the new exchange should be kept under careful observation, and the fault form recommended by Mr. Elliott is eminently suitable for the purpose and will promptly reveal any weakness in the working of the new system. It is considered that a successful transfer is one in which the total number of faults arising therefrom does not exceed from 0·2 per cent to 0·5 per cent of the total number of lines transferred.

Mr. Hovey refers, from the subscriber's point of view, to the change of telephone number which in some cases becomes necessary when an exchange transfer is effected. It is agreed that a change of telephone number may cause difficulty to the subscriber, but such changes are highly objectionable from the point of view of the telephone administration also, and result in considerable inconvenience and expense in bringing them into effect. Changes of number are consequently not made without sufficiently good reason. A telephone-exchange transfer is an example of an engineering operation where change of number and, in some cases, change in name of exchange cannot always be avoided. Careful arrangements are made to safeguard the subscriber's interests when his number is changed, and measures are taken to ensure that any subscriber calling for the old number may be given connection to the subscriber wanted. This is partly secured by reserving the old number in disuse for a definite period until a new issue of the directory is published. Extensive alterations in subscribers' numbers caused by a large transfer may necessitate the issue of a new telephone directory at the date of transfer.

DISCUSSION ON "SWITCHGEAR STANDARDIZATION."*

NEWCASTLE LOCAL SECTION, 11 MARCH, 1918.

Mr. R. W. Gregory: I agree with the author that consideration ought to be given to the standardization of switchgear. The effect of recognized standardization is generally increased output, and increased national output means increased national income, a very desirable objective. I think, however, it is only desirable to standardize such apparatus or parts of apparatus the designs of which are known to meet satisfactorily present-day requirements, and will, as far as can be judged, meet the requirements of the art for some time to come. Under this heading I would include, knife switches, back-connection studs, nuts, screw threads, ratings of current-carrying conductors, brush contacts, terminals, and a great deal of low-voltage switchgear apparatus which has proved itself to be satisfactory in everyday operation, and the design of which cannot be materially affected by the huge developments in power supply expected in the future. On the other hand I do not think it desirable to standardize such apparatus as high-tension oil switches for the control of large powers, and the arrangement of high-tension switchgear. The arrangement of switchgear put forward by the Swiss Commission is, to my mind, an excellent example of the unhappy results of premature standardization. It has been common knowledge for some considerable time that when an oil switch breaks large powers an explosion is obtained, and, so far as we can judge, so long as switches are used which break circuit by the parting of hard metal contacts submerged in oil, this explosion will always result. Yet manufacturers have been so tied by their standard dimensions of cubicles, standard top plates, standard operating gear, etc., that very few of them have ever attempted to design their switches to contain this explosion, although the mechanical problem they had to solve to make the switch sound in this respect is not one of great difficulty. Switchgear arrangements therefore have so far been settled by the fact that the oil switch may at any time explode, and with this in view the arrangement put forward by the Swiss Commission is quite logical. The author refers in favourable terms to the cellular arrangement of switchgear and invites discussion thereon. Are we to gather from this that he thinks this type of switchgear should be that included in the Standard Specification? I agree with him that the cellular type of gear is quite good if it is properly arranged, but how few of the cellular arrangements are really safe and sound and meet all the requirements of good switchgear. I feel that as long as weak switches and bare conductors are used the cellular type will never meet completely the requirements of heavy power switchgear. To my mind, switchgear is not good enough if it is exposed to the troubles of short-circuit from conducting fumes, rats, vermin, and dirty insulators, and which is a potential source of danger to human life. There is no engineering reason why any high-tension switchgear —for the voltages likely to obtain in this country at least—should have a bare conductor in its composition. A switchgear that has each and all of its high-pressure conductors insulated and enclosed in an earthed metal sheath would not only be safe to operate but, in view of the small possibility of a short-circuit between phases, would be a safe piece of apparatus to have on a large system. It could be made a compact mechanical and electrical job, and at the same time bring the switchgear on a line with the best achievement of electrical engineers, namely, the lead-covered cable. If the final outcome of this paper is a Standard Specification for British high-tension switchgear, I would suggest that the Committee who draw up this Specification should avoid slavish adaptation of German, Swiss, or American standards and designs. The best of these do not entirely suit us. Within our limitations and for our own purposes, we, as an engineering nation, can and do beat all comers in switchgear design, and if we are out for the export trade, it will not be good enough for us to say that our standard gear is equal to that which can be bought in Germany or America; we must offer a better article.

Mr. H. W. Clothier: On the general question as to the desirability of standardization, I agree with the author, but it must be accomplished in such a way that it does not put an embargo on the inventive ability of the individual—a heritage of the British which stands out boldly in the engineering developments of all nations. The need for a regular revision of standards should be acknowledged, and such revisions must not be under the sole control either of a monopoly or even a majority of parties with vested interests. Also it seems to me that a standard specification must allow a certain amount of latitude, possibly by the inclusion of alternatives. For instance, wall plugs would seem to be very simple to standardize; the centres and sizes of pins are very necessary. One British make of plug is provided with a projecting sleeve or petticoat with the object of rendering it impossible to touch a live conductor in any position of the plug. There is a difficulty in standardizing this feature because the majority of firms do not make their sockets of a suitable external diameter to allow the plug to pass over. Must the minority struggle on alone, or is this original detail in design, which has distinctive merit, to be lost? I think the least that should be done in such a case is to make the specification allow the alternative. I think also we must take care we do not sacrifice any of our national characteristics in design by trusting too much the example of practices set by our foreign competitors. It is a natural but dangerous tendency to take an established set of rules, such as those prepared by the V.D.E., and to depend too

* Paper by Dr. C. C. Garrard (see page 213).

much upon them. I think we must remember that in them there is a taint of autocratic monopoly from which we would be spared. I remember a few months before the war a German made the audacious proposal to me that my firm should purchase their switches from Germany rather than continue to manufacture their own. Fortunately there was no need to give the proposal the slightest encouragement. Despite the specifications, publications, and advertised testing plant, I believe we have British experience of the best kind to direct our developments. No amount of testing plant can tell so much as a really bad short-circuit on systems such as we have in this district with over 100,000 kw. of plant connected in parallel on one huge network. There is doubtless much room for reform and, as the author suggests, the collation of experience and theory, but we have no cause to think that we are behind in switchgear design just because we cannot display elaborate and expensive institutions for "research." Our research has been done in another way. It may be a better way for the fact that there has been individual freedom and the user has been an independent party not under the rule of a manufacturing monopoly. The author instances the case of the lightning arrester invented in England but developed in America. I contend that this is an example of the advanced state of the art in Great Britain. Lightning arresters have been developed in this district practically out of existence, which is the ideal. To imagine that any puny apparatus we make will arrest lightning is the wrong way to approach the subject. The effect of lightning is to put a short-circuit upon that section of the line nearest to the part struck. All apparatus including transformers and switchgear, therefore, must have the requisite strength of structure to withstand the short-circuit. The development of suitable switchgear and protective devices, which must be there in any case to deal with other kinds of short-circuits, seems to be the best method of dealing with the effects of lightning. As to the "most beneficial principles of high-tension switchgear construction," in the stage of evolution we have reached a complete enclosure of all conductors within metal, which is a step in advance of the enclosure on three sides only as obtained by the usual cellular construction. The difficulties experienced in cellular construction leading to the further enclosure have been :—Loss of life and injuries due to contact with bare conductors ; loss of life and burns due to flames projecting from cells ; excessive cost of efficient interlocking features ; risk of arcing between conductors and across insulators exposed to gases and vapours ; excessive costs of building construction required to provide for spacious cells and numerous compartments. On the whole I think much has been achieved in this country by independent and individual enterprise, and I look for a promising future when these efforts are strengthened by collective action on British lines.

Mr. A. Collins : In the present state of the art, standardization of switchgear must be approached with caution, although on the general question I am in agreement with the author. A certain amount of work is possible in connection with low-tension switchgear, but as far as high-tension switchgear is concerned, we must be content at present to deal only with ratings and tests. I hope that British Standardization Rules will be based upon British practice and experience, and that there will be no tendency to take foreign specifications and with slight modifications reproduce them as so-called British Standards. British designers have a large amount of experience to justify their present designs, and to sink their identity in foreign-made rules would be nothing short of a calamity. By way of illustration, I would draw attention to the standard test pressure for switchgear recommended by the author on page 214. It is suggested that we should take the American Standardization Rule as it stands. We should certainly not accept this without going further into the matter, as a large amount of switchgear manufactured in this country for use on some of the most important systems is designed to withstand a pressure test of three times the working pressure. One objection I have to the American Rule is that the factor of safety is reduced with higher working pressures. I would also draw attention to the following note which appears at the end of the American Standardization Rule No. 728 : "In some systems it has been found that the pressure rises so high during switching that higher insulation tests than that specified . . . should be given." This in itself suggests the desirability of a higher factor of safety, as it is difficult to predetermine the extent of such pressure-rises. It is true that in this country with comparatively low voltages and dense cable systems, pressure-rises during switching operations are rare. The phenomenon, however, must always be present to a certain extent, and with higher voltages and longer overhead lines it will be in greater evidence, and I think that the test that has been largely used in British designs should be retained in this country, thus giving us an increased factor of safety which, if we adopt the American Rule, would be sacrificed. The argument advanced against recommendations of this nature is that if we adopt more conservative ratings than other countries we shall suffer by foreign competition. This is the wrong spirit in which to approach the matter, and it should be remembered that the expression "British Standard" has always had international significance. Further, we have a reputation for "continuity of supply" superior to other countries. By maintaining our high national standards, British switchgear will sell on its merits in the same way as the productions of other branches of engineering have done in the past. Fig. 7 shows the relation between voltage and length of break in oil switches, and this curve the author states "may be taken as typical of present-day designs." It would be of interest if he could give us some idea of the upper and lower limits of the figures from which this curve has been averaged. I believe that different manufacturers' figures vary over wide limits, and if this is so it would not appear desirable to give a curve claiming to be typical of present-day designs. There are a number of other factors besides the voltage which determine the most suitable length of break. Among these is the current to be broken, and I do not think that even for one manufacturer's line of switches such a curve would be possible. Probably a closer relation-

ship could be obtained between breaking capacity and length of break. In connection with the speed of operation of oil switches, in addition to the two points mentioned by the author, there is a third important point to be considered. This is what may be called the "inherent time lag" of a switch, as distinct from any time lag obtained by the use of time-limit devices. I refer here to the time which elapses between the occurrence of the fault and the separation of the switch contacts, the point indicated on the interesting speed curves which the author has shown us. This is an important property of an oil switch, as it is generally desirable that switchgear should operate as nearly instantaneously as possible, otherwise trouble may be experienced due to synchronous plant dropping out of step; and this property also has considerable bearing on the rating of an oil switch. Owing to the drooping nature of the short-circuit transient, a switch with a long time lag will normally clear a fault successfully and yet be of smaller breaking capacity than a quicker acting switch when connected to a given amount of plant. In other words, advantage can be taken of the slow action of the switch, which may prove to be a disadvantage, to give what is after all only an apparent increased rating. This practice is not to be recommended, as conditions may arise, such as resonance or a high-resistance fault developing into a dead short-circuit at the instant the switch contacts separate, when the short-circuit current will be much heavier than that which may be normally anticipated. Under these conditions, the slow-acting switch with a smaller factor of safety is at an obvious disadvantage. In conclusion I should like to refer to the author's preference for the cellular or cubicle type of construction, as opposed to what is generally known as the solid or ironclad construction. It is unfortunate that as an illustration he has selected drawings from a Swiss Report. I am pleased to see that he does not appear to be satisfied with the details of the scheme shown in Figs. 15 and 16. Reference is also made to the possibility of trouble from "conducting fumes" and "the effect of arcs which have been set up as the result of accidents." Here the author emphasizes the main electrical disadvantages of the type of construction he advocates. By enclosing all the conductors in insulating compound these troubles are eliminated and complete immunity from breakdown can be secured. Routine maintenance work is reduced to a minimum, being confined entirely to the switch contacts and relays, and can be carried out with perfect safety as a result of the simple automatic interlocking which is the direct consequence of the draw-out principle. It is impossible for an operator to receive a burn or shock. Elaborate and ingenious interlocking schemes have been devised for cellular-type switchgear, but these are at the best complicated and expensive and liable to get out of order, interruption of supply and often danger to life being the consequence. The saving in cost of the building if the solid construction is adopted has also to be considered. Taking as an example a typical 20,000-volt substation equipment, the space occupied by the cell-type construction is approximately seven times that of the ironclad type, and in addition the latter type requires no cell work or special building work of any nature whatsoever.

Mr. R. M. Longman: Regarding the type of switch contact illustrated in Fig. 1, possibly it would be advisable to groove the knife of the switch. The contact would be cleaned better, the pressure per square inch would be greater, and the slot would allow a current of air through the contacts. I have often noticed in large current-carrying capacity low-tension gear that sufficient attention is not paid to heating and the gear is not suitably placed to keep cool. On page 216 the question of nuts is taken up and I think the author is on the right lines, but I wish that manufacturers would always provide suitable spanners for the nuts, otherwise the nuts get badly mutilated. Fig. 5 shows resistance and reactance types of circuit-breakers and I should like to know whether the author really advocates them and whether he thinks it is suitable and safe to put reactances or resistances in such switchgear. Personally I think provision ought to be made for resistances or reactances apart from the switches, as the interior of the switch is by no means the correct place. Fig. 14 shows the millivolt drop across bolted contacts, and whilst this is a better result than is often found in practice I do not consider it to be good enough—it should be a falling curve with increasing current so as to keep down the watts lost. Referring to the pressure-test rules, I think we should not be too hard on the Americans as they make provision for higher voltages than we shall ever have to use.

Mr. F. Coates: The paper should have been entitled "Switchgear Design" as it seems to deal more with that than with standardization. I agree with the proposal to standardize brass and gunmetal alloys, and I should like to know if the specification suggested gives the maximum conductivity. With regard to surface density and current densities in conductors, I do not think we need worry so much about these, as the temperature limit would take these points into consideration. Something should have been mentioned about the length of creeping surfaces on porcelain insulators, and the arcing distances between bare conductors and earth.

Professor W. M. Thornton: There are many things that occur in the question of standardization. For instance, one must specify at what part of the cycle the break is to occur, a crest value or a zero value. Can one compare a switch which has broken an ordinary symmetrical current safely with one breaking under short-circuit conditions, in which there is certainly an initial high value and in the case of three-phase current possibly a complete shift of the wave to one side of zero, on two phases at least? It would be extremely difficult to standardize switches except by most extensive experiment. The author refers to the question of a Government Testing Laboratory in which this might be done, and I am sure that the Research Department will put down any sum needful if the manufacturers will contribute an equal amount; that is their usual condition. Fig. 7 gives a curve connecting total length of break and voltage. This of course depends on the number of breaks in series per phase. Fig. 8 connects quantity of oil and breaking capacity,

but I do not quite see how the volume of oil affects this. It seems to me more a question of head of oil, and it does not matter in the least what the total quantity is except that the larger the tank the larger the air-cushion space above the oil, and this depends greatly on the design. Fig. 14 refers to millivolts drop at an interlaced copper joint. I can give an example from an electric furnace having 13,000 amperes per phase where the drop across such a joint heavily bolted up was $7\frac{1}{2}$ millivolts. With reference to "explosions" of switches, it is possible to have all the force of a gas explosion during the formation of the gas cavity around the arc, without a true explosion at all. It would be extremely difficult to test lightning protective gear under working conditions, for the breakdown strength of air depends on the frequency, which in the case of lightning is millions a second. So far as I know there is no relation established between voltage and spark length at these high frequencies.

Mr. W. G. Guns: The author advocates a uniform thickness of $\frac{1}{8}$ inch for busbar strips, and yet in Fig. 13 gives as one size 2 inches $\times$ 5/32 inch; surely this is not consistent with standardization.

Mr. T. Carter: On page 215 the author suggests certain rod diameters of studs which appear to be based on a uniform current density in the rod of 1,000 amperes per square inch. This does not seem to be in accordance with the well-known rule of Current $\propto d^3$, which leads to a reduction in density as the current increases, or vice versa. The Institution table of cable capacities is an excellent example of the application of the principle, small sizes being worked at much over 1,000 amperes per square inch and large sizes at much under that value. The matter of standardization is so important that all possible anomalies must be avoided at the very start, and Table 1 certainly does seem to need reconsideration. In Table 2 the suggested thickness of the nuts, C, is probably too small. I note that they are proposed to be made in brass and not in copper, but standard switches are already made with copper nuts about 50 per cent thicker than dimension C indicates. In Fig. 13 certain busbar connections are suggested. To fix 11/16 inch $\times$ 3/32 inch as a standard seems to me quite absurd, when it would be easy to have rounder numbers. I think also that it would be very much better to keep to tenths and half-tenths in thickness, rather than to use eighths of an inch. The line of switches previously suggested is based on even hundreds of amperes, but none of the sections given are anything like even hundredths of an inch. It is scarcely necessary to standardize anything narrower than one inch, because after a narrower strip is drilled for taking a stem, there is very little section left; and it is necessary to have more than one thickness—for each of the greater widths at any rate—so as to be able to taper off the bars suitably. I should suggest using, as widths, 1 inch, $1\frac{1}{2}$ inches, 2 inches, $2\frac{1}{2}$ inches, 3 inches, and 4 inches, and carrying in stock both 0·10 inch and 0·05 inch thick material in each width. I heartily approve of the principle of standardization, and have put forward these suggestions as possible means of improving the proposals of the author in the details referred to.

Mr. J. R. Beard: I agree with the previous speakers that any question of standardization of extra-high-pressure apparatus should be approached with great caution. In particular I doubt whether the time is ripe to standardize such points as the length and number of breaks in the oil switch, cubicle constructional arrangements, or lightning-arrester gear. On page 219, for example, the author states that if there are two breaks per phase the circuit is being opened at twice the speed of the mechanism, the implication being that a two-break switch is faster and better than a single-break one. While this may be so, I have heard very good reasons put forward for the exact reverse of this, namely, that the two-break switch has a less rupturing capacity than the single-break one. Again as regards lightning-arrester gear, our experience in this district has led us to abandon entirely the use of such apparatus for high voltages, and for the protection of substation apparatus we rely instead on terminating each overhead line with 100 or 200 yards of cable. While Mr. Bernard Price in South Africa does not go so far as to condemn the use of lightning-arrester gear, he states that he has no experience to show that it is productive of any good results. In this connection I recently heard from a man who had been visiting the 100,000-volt installations in California, that he found all the arrester gear cut out of circuit. Turning now to points which I think do lend themselves to standardization, the first and most important one which occurs to me is the question of pressure tests, but I do not quite agree with the figures proposed by the author. The switchboard should be at least as safe and sound a job as the cable it is connected to, even more so in fact, as a switchgear fault is usually a busbar fault. I suggest therefore three times working pressure for switchgear depending on insulation other than air, while for air insulation the test pressure should in my opinion be not less than five times, since air insulation has no margin of dielectric stress to resist surge pressures. This distinction between pressure tests for air and other forms of insulation is quite general on other work such as cables and overhead lines. The next important point is the standardization of the dimensions and pressure-drops of ammeter and instrument shunts, and of current and potential ratios. Fuses, again, lend themselves readily to standardization, particularly as I think the author is not quite correct in assuming that in the future the conditions on distributing networks will be increasingly severe. On the contrary, I think the tendency will be for distribution systems in the dense areas to consist of a number of separate alternating-current networks, and even if continuous current be retained I think the bigger networks will be largely sectioned. Types of apparatus in which standardization would help immensely are auto-transformers, controllers, and motor starting gear generally, and I was much disappointed to note the small space devoted to this question in the paper. I see no reason why the temperature rise on switchgear should not be standardized, but I do not follow the author in his suggestions that higher temperature rises are permissible with the larger currents or in the neighbourhood of shunts. If they are permissible in these special

cases, surely they should be permissible all round. Apart from the apparatus itself a standard nomenclature might usefully be adopted; I have in mind particularly the somewhat indiscriminate use throughout the paper of the terms "fuse" and "cut-out," and also the alternative terms "automatic oil switch" and "oil circuit-breaker," which are in common use.

Mr. W. T. Maccall: I agree with other speakers that high-tension switchgear is not yet ready for standardization, but low-tension switchgear should be standardized to a much greater extent than at present. I think it desirable to specify the millivolt drop at contacts, leaving the manufacturers to obtain this in the way they think best with any current density they like to use. This is an example of the better method of standardization, viz. specifying results, as against the poorer method of specifying the means to be adopted. But why should a large switch be allowed (see Fig. 2) a higher voltage drop than a small switch? In Table 1 the apparent current density is approximately constant, whereas, as Mr. Carter has pointed out, higher densities should be allowed on the smaller sizes. This point is, however, partly covered by the effect of the thread. The current density taken on the section at the bottom of the threads is greater on the smaller sizes. The variation may not be as much as it should be, but is considerable. With regard to the actual threads, I suggest that above 1·3 inch diameter the present standards for gas and water pipes be adopted, as these have 11 threads per inch. This would leave only five sizes requiring new standards, and even for some of these either the Whitworth or the gas thread might be adopted. The author states that the curve in Fig. 12 "approaches a vertical asymptote, the value of which is the fusing current." I do not think that this statement is correct. The slope increases continuously but has a finite limiting value, i.e. even at 100 per cent of fusing current the curve does not become vertical. The alternative method of determining the fusing current shown in Fig. 11 therefore appears better, for in this case the curve does approach asymptotically the horizontal line which represents normal fusing current. In Fig. 13 the section 2 inches × 5/32 inch should be replaced by one $2\frac{1}{2}$ inches × $\frac{1}{8}$ inch so as to retain a uniform thickness.

Mr. G. L. Porter (*communicated*): Switchgear may be defined as having two independent functions to perform, viz. interconnection and interruption. The former is easy to study and specify, and such details as are concerned with this function only can quite well be standardized. They include instruments and their transformers or shunts, form of terminals, thread, nuts, etc., of terminal bolts, length of leakage path of porcelain insulators, pressure tests. As regards current-carrying capacity of conductors, it seems to me that it is wrong to standardize either amperes per square inch or pressure drop and ignore in what manner the heat is being dissipated. Maximum temperature rise seems the only safe thing to standardize. It is when we consider the function of "interruption" that we find standardization out of the question—at any rate in oil-break switches. The subject is so little understood and so difficult to study. Experiments cannot be carried out on the necessary scale except at great cost and risk. The results of actual commercial use are mainly negative, and real comparisons of different designs cannot be made, seeing that no two switches may ever have to interrupt the circuit under exactly the same conditions of fault and of plant capacity. As a result, present oil-switch design is not founded on anything sufficiently exact for it to be a fit subject for standardization. However, there is a great need for an oil-switch specification, the four leading factors being:—(1) Voltage, (2) amperes at standard maximum temperature rise, (3) maximum instantaneous short-circuit current, (4) time interval between closing of trip circuit and parting of switch contacts. The larger the value of (3) and the smaller the value of (4) the better the switch has to be.

Mr. S. A. Stigant (*communicated*): I wish to join issue with the author on the question of lightning protective gear. This sub-section of switch and control gear has been perhaps the most neglected of any in this country, although more attention has been directed to it in the foreign countries mentioned by the author. There is, however, far from cohesion of opinion with regard to details of design, action, and location of this class of apparatus, and it is significant that the latest published report * of the American Institute Committee on "Protective Apparatus" does not for the present suggest the standardization of lightning protective gear. It certainly does not seem to be a wise proposition to standardize as yet in this country where so little has been done. The second Report of the Swiss Commission referred to by the author is one of the fullest and best reports on the subject, and would be valuable for building up Standardization Rules. Coming now to details in the paper and taking, first, horn-gap arresters. In some the horns diverge gradually, and are straight almost from root to tip, while with others they branch away rapidly and are curved. At the root, the horns are in some cases quite parallel and in others each horn bends away at an angle of about 45 degrees. In this type of apparatus these are important points, and it would seem that some ruling on the matter should be laid down when formulating possible rules. Then as regards arrester earthing resistances; should these be of such a value as to make the arrester reasonably non-arcing, thereby maintaining the high voltage at the point of possible danger longer than is desirable, or should it be such as to relieve the apparatus to be protected in the shortest possible time? In connection with choke coils, the author mentions the differences of opinion that exist regarding adequate sizes for protective purposes. This is a matter which needs particular attention, for the coils often met with in practice are not of the slightest use for the protection of adjacent machines. These coils have an inductance of anything up to 0·02 millihenry and their use is a menace to the system rather than otherwise, on account of the false sense of security they create. A choke coil may be chosen from two different view points of protection, either of which is a determining factor in its size. It may either be used in conjunction with

* *Proceedings of the American Institute of Electrical Engineers*, 1916, vol. 35, p. 1533.

a lightning arrester, its function being to hold back a disturbing wave until the arrester can discharge the disturbance, or it may be used alone, in which case it must be of sufficient size materially to smooth down the transmitted wave passing through to the machine behind it. In the former case, the inductance might range from 0·025 to 0·2 millihenry, but in the second case the coils need to be much larger. So long as the inductance of the coil is specified it is doubtful whether it would be wise to limit in any way the constructional details such as shape, diameter, number of turns and spacing between turns, though tentative figures might be suggested. Both indoor and outdoor types of coils would have to be considered, and there is no more reason for fixing the spacing between turns of the latter than with the former. Rather the reverse, in fact, for with air-insulated coils a breakdown between turns is momentary and self-healing, while in the case of coils having fibrous insulation the damage would be permanent and the coil would need re-insulating. The electrolytic arrester has been developed to some considerable extent, and is practically the only piece of apparatus which could at present be standardized. The same remarks would, of course, apply to the arcing horns as outlined for ordinary horn-gap arresters. High-voltage protective condensers are far from being in a state when standardization would be a benefit. There are but two practicable constructions on the market, the Moscicki and the Meirowsky, both of these possessing the disadvantages of series fuses connected to each element. These static condensers have found the greatest favour on the Continent, though they have been installed, in isolated cases, in this country. As in the case of choke coils their requisite size (microfarad capacity) has not by any means been agreed upon by designing and operating engineers, and until more uniform opinions are held true standardization is impossible. An Institution Committee by collecting data, arranging for the reading of papers, and collaborating with existing bodies carrying on similar work, such as the American Institute, could bring order out of the present chaotic state of affairs and so ensure a firm basis upon which future Standardization Rules might be built.

Dr. C. C. Garrard (*in reply*): One of the most important aspects of the question of standardization is the help it will be undoubtedly in increasing the productivity of the country in the future. If we are to bear without distress the great weight of debt which will result from the war, an increase of production is absolutely necessary. I am convinced that, given proper organization, as far as engineering workshops are concerned the limits of increase of production per man are not within sight. Standardization is an essential in this connection. As I have maintained elsewhere, the standardization I have in view does not hinder progress.

Several speakers, among them Mr. Gregory and Mr. Collins, attacked the cellular type of construction, and, if I understood Mr. Gregory correctly, he contended that this was a foreign type of construction. On the contrary, however, I think it may be stated that the cellular form of construction was not only a British invention but is essentially a British type of design. Hitherto the usual type of Continental high-tension switchboard has been without cells at all, and has consisted of entirely open oil switches, busbars, etc. It is because Continental engineers have found out the disadvantages of this type of construction that they are coming over to the cellular type. I am at one with these several speakers in their contention that it is an advantage to cover up the bare connections. This is particularly so with the connections which go to the oil-switch terminals. It is an advantage under all circumstances to cover these up in some way so that no bare metal is exposed between which an arc may form. Between the oil switch, however, and the busbars and isolating links there should be introduced a division which should be as air-tight as possible. It has been the practice in the past, in some cases, to have such a division with holes in the same through which connections pass. Such holes should be made quite tight. If this is arranged, then it is not so necessary to cover up the connections above the division. The main advantages, however, of the cellular construction are: (1) That in the event of any trouble the fault is confined solely to the section involved. It may be contended that a fault should not happen, and with perfect switchgear this may be so; but with a perfect design there is such a thing as careless upkeep, and therefore a second line of defence is advisable. (2) With an oil switch not confined in a cubicle, in the event of an oil tank blowing off there is very great danger to life to anybody standing near.

Mr. Gregory suggests that the National Physical Laboratory might take up the question of tests on oil switches. As far as I know, however, they have not sufficient facilities, and personally I do not think very much can be done until we have a National High-Tension Laboratory properly equipped. I suppose the only thing to be done is to keep on agitating until we get what we want.

Mr. Gregory also suggested, quite rightly, that with some types of switches the speed of operation is quicker when operating on short-circuit current. This is due to the electromagnetic forces operating within the switch, and is the case with a switch consisting of a horizontal cross-arm which falls from its contacts in breaking circuit. As regards the speed of break, for a switch having a double break, a velocity of movement of the mechanical parts of 5 feet per second at the instant of break is a good result.

Mr. Collins raises the question of test pressure. I would point out that the higher the working voltage the lower the factor of safety must necessarily be as regards test voltage. It is important, in view of international competition, not to set up too high a test pressure as a standard, and I think the figures I have suggested give a reasonable degree of excellence without handicapping ourselves.

I admit that Fig. 7 does not give the whole of the facts for determining the length of break of oil switches. It is simply one aspect. Personally I regard the figures obtainable from Fig. 7 as being the minimum length of break which should be used. Larger lengths may be used if circumstances demand it.

Mr. Collins and Professor Thornton raise the thorny question of the rating of oil switches. As I have indicated, this matter is being considered by the standardizing authority, and I think we cannot do better than await the publication of their conclusions. Professor Thornton also mentioned the great importance of the head of oil above the break. I quite admit this. I must say, however, that I think the view I have expressed that as the oil is the medium for taking up the heat energy at the break the quantity of oil must be considered in this connection. If I understood Professor Thornton correctly, he is of the opinion that gas explosions in the space above the oil could not cause any damage, as the maximum pressure to be expected would not exceed 100 lb. per square inch. Even this pressure in some switches I am at present concerned with would give a pull on the tank-supporting bolts of each phase of 40 tons. This shows the necessity of strong construction. I must say, however, that I agree with Professor Thornton in that I do not think it is the vapour explosion above the oil which causes the severe phenomena of which one hears occasionally. Dr. Steinmetz some years ago likened the action of an oil switch to a charge of dynamite going off within the tank. I think there is a lot of truth in this.

I am quite unable to follow Mr. Beard in his suggestion that the breaking capacity of an oil switch varies inversely with the number of breaks. I think this is quite contrary to experience. As regards his remarks regarding the necessity of standardization of auto-transformers, current and potential transformers, ammeter and instrument shunts, I am at one with him. As a matter of fact some of these items are now being dealt with.

Several speakers have mentioned the copper sections shown in Fig. 13. First of all I should like to say, in answer to Mr. Gregory, that from the point of view of the expansion of copper busbars due to heat the use of soft copper and relatively thin sections is an advantage. These will buckle slightly under the influence of heat and not cause any mechanical damage. Mr. Guns and Mr. Maccall suggested a section of $2\frac{1}{2}$ inches $\times \frac{1}{8}$ inch instead of 2 inches $\times$ 5/32 inch. I think with them that this would be an improvement. Mr. Carter suggested still thinner busbars than I have recommended, viz. 1/10 inch. I think this would add to the difficulty of building up connections with no adequate advantage. As regards the use of strip $\frac{5}{8}$ inch wide, this is often used on small distribution boards.

Mr. Carter also thought that the connection nuts shown in Fig. 4 are too thin, but I would point out that if we use the thinner busbars suggested by him then thinner nuts will be necessary unless considerable space be wasted. He also raised the question of the current density in the studs and advocated as a basis of the design an equal dissipation of watts per square inch for all sizes. I am afraid it would not do to base our designs on this principle alone, as it would result, in the case of small current apparatus, in very fragile and unmechanical designs. Mr. Beard also raised the question as to why the temperature limits should be allowed to be higher on larger current apparatus. To a certain extent this is a concession to necessity. With large current apparatus it is difficult, without an excessive use of metal, to get the low temperature limit which is easily obtainable with good workmanship on small apparatus. These remarks also answer one of the other points raised by Mr. Maccall, although I am at one with him in his contention that the user should simply specify the millivolt drop of a switch and leave it to the maker to get this how he can. The great danger in all these matters is to follow one rule blindly.

I think very much could be done with regard to the question of millivolt drop, especially when dealing with large currents. This question was raised by Mr. Coates in connection with the relationship between temperature rise and pressure drop at the joints.

Professor Thornton spoke on the question of reactances used with switches, as illustrated in Fig. 6. These reactances perform a different function from the power-limiting reactances which have been dealt with recently in a paper (see page 269) by Mr. Wedmore before the Institution. These latter are always in circuit and their object is to limit the rush of current on short-circuit. The reactances, or resistances, used with switches, as in Fig. 6, however, are only in circuit a fraction of a second, and their object is to limit the rush of magnetizing current when switching in a machine or transformer.

Both Professor Thornton and Mr. Beard raise the question of lightning arresters. I agree with Professor Thornton that it is not possible to make tests approaching the nature of lightning; nevertheless I think laboratory arrangements can be made whereby it is quite possible to discriminate between the different forms of lightning arresters and to secure a criterion of their usefulness.

PROCEEDINGS OF THE INSTITUTION.

609TH ORDINARY MEETING, 21 MARCH, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 7th March, 1918, were taken as read, and were confirmed and signed.

Mr. C. P. Sparks, Past President, presented to the Institution an oil portrait of Galileo made by W. Bradley about 1825 from the original by Susterman in 1635, and now in the Uffizi Gallery, Florence. The President accepted the gift on behalf of the Institution, and the cordial thanks of the meeting were accorded to Mr. Sparks for his generous gift.

A paper by Dr. S. F. Barclay, Associate Member, entitled "The Mechanical Design and Specification of the Turbo-Alternator Rotor," was read and discussed, and the meeting adjourned at 8 p.m.

610TH ORDINARY MEETING, 11 APRIL, 1918.

(Joint Meeting with the Electrical Section of the Royal Society of Medicine held at the Cancer Hospital, Fulham, S.W.)

Mr. C. H. WORDINGHAM, President, took the chair at 7.30 p.m.

The minutes of the Ordinary Meeting of the 21st March, 1918, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read, and was ordered to be suspended in the Hall.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors:—

Benevolent Fund: S. Insull, J. E. Kingsbury, W. Lang, J. R. P. Lunn, A. J. Newman, S. Sharp, J. F. Shipley, W. C. P. Tapper, and J. H. Tonge.

Building Fund: M. L. Delanoy.

Library: Messrs. Constable & Co., Ltd., The United States Department of Commerce, and Messrs. Wyman & Sons, Ltd.

A paper by Dr. E. P. Cumberbatch entitled "Diathermy: the Use of the Electrical Current to raise the Temperature of the Body in the Treatment of Disease" (see page 349) and one by Dr. R. Knox entitled "Single-impulse (Instantaneous) Radiography; its Possibilities and Limitations" (see page 352) were read and discussed, and the meeting adjourned at 9.45 p.m.

The members then inspected the Laboratories of the Cancer Research Institute which were open by permission of Dr. Paine, the Director. There were also on view various pieces of electro-medical apparatus supplied by manufacturers.

611TH ORDINARY MEETING, 18 APRIL, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Joint Meeting with the Electrical Section of the Royal Society of Medicine, held on the 11th April, 1918, were taken as read, and were confirmed and signed.

Messrs. R. J. Kaula and J. R. Dick were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

Bowman, Joseph Matthews.
Judson, Daniel, J.P.
Julius, Charles Henri.

Associate Members.

Bellamy, Revill Fenton.
Bennett, Harold Sydney.
Davidson, George Francis.
Harvey, John Roland.
Hooper, Henry.
Hunt, Francis Cecil.
Inglis, Joseph Jeffrey.
Jarvis, Edward James
Jensen, Niels Christian F.
Lund, Charles John.
Manson, John Cormack.
Mather, Richard Henry.
Parry, Fred.
Paterson, Hugh.
Plant, Stanley George.
Prentice, John.
Sherratt, Jun., Thomas.
Slingo, Percy Edward.
Tofield, Hugh Clifford.
Truman, Herbert Charles.
Watson, Edward Clifford, Lt.-Commander, R.N.
Wood, Walter Ashley.
Wordley, Walter Alfred.

Associate.

Mackenzie, Thomas Brown

Graduates.

Daddow, Albert John.
Dalton, Oswald Lancelot.
Hamid, Khwaja Abdul.
Higham, Ralph Gilson.
Ingersley, Kay.
Macdonald, Miss Morag Clementine.
Pedersen, Jens David F.
Podbury, Walter Percival.
Reed, Victor.
Steffelaar, Johannes Marie.
Vine, Bertram James.

Students.

Bickell, Stanley Fendey.
Brown, Jun., Robert Calvert.
Champney, Laurence.
Coleman, Dermott Trevor.
Cramp, Alfred Cecil.
Drury, William George R.
Hughes, Hugh Gordon.
Ives, Charles William F.
Payne, George Lewis.
Peasgood, jnr., Frank.
Rhenms, Stanhope Theodore.
Smith, William Francis.
Spilsbury, Robert Samuel J.

TRANSFERS.

Associate Member to Member.

Levin, Arthur Everard.
Read, Herbert James.
Stokes, Harry Potts.
Taylor, Joseph.
Wood, William John H.

Associate to Member.

Dixon, Lewis William.

Graduate to Associate Member.

Murray, John Bernard.

Student to Associate Member.

Schamasch, Albert.

Student to Associate.

Delanoy, M. Lee.

Student to Graduate.

Kidvai, Sarmar Ali.
Orme Basil Shelton.
Rau, M.R. Raja, B.A.
Rawlings, William John.
Wells, Reginald Iredale.
Wilson, Francis Joseph H.

A paper by Mr. L. Andrews, entitled "The Overseas Distribution of Engineering Appliances" (see page 367), was read and discussed, and the meeting adjourned at 7.58 p.m.

612TH ORDINARY MEETING, 25 APRIL, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 18th April, 1918, were taken as read, and were confirmed and signed.

Messrs. J. O. Girdlestone, F. B. O. Hawes, and S. Sharp were appointed scrutineers of the ballot for the election of new members of Council.

The President read a letter from the Faraday Society inviting members to a discussion on "Co-ordination of Scientific Publications," to be held at the rooms of the Chemical Society on the 7th May.

A paper by Mr. E. C. McKinnon, Associate Member, entitled "Large Batteries for Power Purposes," was read and discussed, and the meeting adjourned at 7.50 p.m.

613TH ORDINARY MEETING, 9 MAY, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 25th April, 1918, were taken as read, and were confirmed and signed.

The President referred to the appointment of Committees to deal with the formation of an Electrical Heating and Cooking Association, an Association for Overseas British Engineering Trade, and an Electrical Appointments Board, and also to draft a Model Maintenance Agreement for Secondary Batteries (see *Institution Notes*, No. 7, p. 26).

A discussion took place on the subject of "A British Electrical Proving House," with an introductory paper by Mr. C. Turnbull, Member, and the meeting adjourned at 8.10 p.m.

614TH ORDINARY MEETING, 23 MAY, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 9th May, 1918, were taken as read, and were confirmed and signed.

The President announced that the scrutineers (Messrs. J. O. Girdlestone, F. B. O. Hawes, and S. Sharp) appointed at the meeting of the 25th April, 1918, had reported to him that they had examined the ballot papers for the election of new members of Council, and that the following had been found to be duly elected :—

President : C. H. WORDINGHAM.
Vice-Presidents : W. A. Chamen and R. A. Chattock.
Honorary Treasurer : J. E. Kingsbury.
Ordinary Members of Council : H. W. Clothier, D. N. Dunlop, Sir R. A. Hadfield, Bart., F.R.S., Prof. E. W. Marchant, D.Sc., C. C. Paterson, and J. Sayers.

A vote of thanks was passed to the scrutineers.

The President mentioned that a Committee had been appointed of the parties interested with a view to watching the situation in regard to the rationing of coal, gas, and electrical energy, and that steps had already been taken to put the views of the Committee before the proper authorities.

A paper by Professor E. W. Marchant, Member, entitled "Some Transient Phenomena in Electrical Supply Systems" (see page 445), was read and discussed, and the meeting adjourned at 7.40 p.m.

THE JOURNAL OF

The Institution of Electrical Engineers

Vol. 56. JULY, 1918. No. 276.

SOME TRANSIENT PHENOMENA IN ELECTRICAL SUPPLY SYSTEMS.

By Professor E. W. MARCHANT, D.Sc., Member.

(*Paper first received 27 October, 1917, and in final form 19 June, 1918; read before* THE INSTITUTION *23 May, and before the* MANCHESTER LOCAL SECTION *12 February, 1918.*)

SUMMARY.

This paper records a number of oscillograms taken on the Liverpool Corporation electric supply system. These include—

(*a*) Current-rushes on switching in transformers of various ratings.
(*b*) Current-rushes on switching in induction motor-generators.
(*c*) Current and pressure transients when high-tension cables are switched on and off, with and without transformers.
(*d*) Current-surges on paralleling alternators, and on synchronizing rotary converters.

In order to explain the results observed on the central station records, a number of tests are included of similar phenomena observed under laboratory conditions, in which the instant of closing circuit has been controlled. The theories of the various transients are discussed, and a bibliography of papers (mostly published since 1913) is included.

INTRODUCTION.

The study of transient phenomena in electrical supply systems has become, with the increasing size of power stations and distributing networks, a subject of growing practical importance to electrical engineers. Such treatises as Steinmetz's "Transient Phenomena and Oscillations" deal exhaustively with the theoretical side of the subject, while the demonstration given by the late Mr. Duddell in his Presidential Address to the Institution in November 1913* on "Pressure Rises" did much to focus the interest of electrical engineers in this country on phenomena which had not, in many cases, been seriously studied. While not attempting in this paper to deal in an exhaustive manner with the whole subject, it is hoped that the demonstration of some of the transients which occur in the everyday working of electrical distributing systems may be of value in drawing attention to current-rushes which may sometimes be overlooked. Nearly all the phenomena described in this paper have been observed by means of the oscillograph, and a considerable portion of the work involved in its preparation has been directed to enable them to be studied under known conditions, and to make them demonstrable and obvious with machines of moderate capacity.

* *Journal I.E.E.*, 1914, vol. 52, p. 1.

STARTING CURRENTS OF TRANSFORMERS.

One of the best-known transient phenomena is that which occurs when a transformer is switched on to an alternating-current supply system. The rush of current when a transformer is first switched on to an alternating-current circuit was first described in a paper read by Professor Fleming before this Institution in 1891, more than 25 years ago.* In the discussion on this paper some interesting experiments on current-rushes are described by Mr. Mordey.† When 100 periods was the standard frequency the phenomenon was usually of no great importance, since in such transformers the flux density in the core was usually kept low in order to avoid overheating; with 50-period transformers also, the phenomenon does not give rise to any very dangerous rushes, but with 25-period transformers worked at flux densities well over half saturation, the current which may flow when the transformer is switched in may be enormous. Steinmetz has shown that with transformers designed for 10,000 lines per square centimetre the current-rush may amount to 400 times the normal magnetizing current if magnetic conditions alone are considered; in practice, the resistance of the coils and the consequent pressure-drop due to such a current will lead to a value of the observed current

* *Journal I.E.E.*, 1892, vol. 21, p. 677.
† *Ibid.*, p. 733.

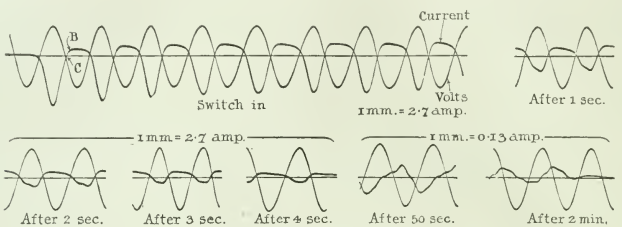
much below this value. In Fig. 1 is shown a current-rush observed on one phase of a 100-kw. 3-phase 6,600-volt transformer of the core type, when switched on near the zero point of the pressure wave.

The rush depends not only on the point of the pressure wave at which the circuit is closed, but also on the remanent magnetism in the iron. For example, if the remanent magnetism is $+5{,}000$ lines per square centimetre (see Fig. 2) the working maximum flux density is $\pm 10{,}000$ and the instant of closing circuit is O (see Fig. 2), when under steady conditions the flux density should be $-10{,}000$, there will be a flux density at the end of a half-period of 25,000 lines per square centimetre; the change in the flux density through the iron in order to provide the necessary counter E.M.F. being 20,000 (i.e. from $-10{,}000$ to $+10{,}000$ under steady conditions), while, in addition, there is the initial remanent magnetism (O A) of 5,000. Under such circumstances the current flowing to the transformer will have to be sufficient to produce this flux density, and may be many hundred times the normal magnetizing current. When the transformer is switched in at the same point of the pressure wave, but with no remanent magnetism, the current-rush may also be a large one.

As a rule the remanent magnetism is not very large if the transformer has been standing idle for some time, but where it is switched in and out at comparatively short intervals the remanent magnetism may be considerable, and the current-rush may vary within wide limits.

The remanent magnetism is usually much greater with lap-jointed transformers than with those having butt joints, since the iron is more easily demagnetized with the latter type.

A number of tests were made on a bank of three 100-kw. step-down transformers switched on to the



(Current 90° out of correct phase.)

FIG. 1.—Switch-in of 3 × 100 kw. Three-Phase Mesh Transformers, 50 periods, 6,600 volts.

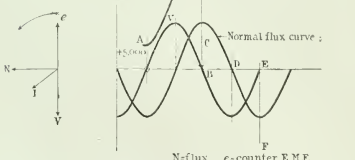


FIG. 2.—Vector diagram.

The remanent magnetism is usually much greater with lap-jointed transformers than with those having butt joints, since the iron is more easily demagnetized with the latter type.

A number of tests were made on a bank of three 100-kw. step-down transformers switched on to the mains. These transformers formed one of two such banks in the Binns-road substation of the Liverpool Corporation, and could be switched on to Lister-drive high-tension feeders by oil-break switches at the substation. The records taken were on one of these transformers. One of these records has been reproduced in Fig. 1. Denoting the three phases by X, Y and Z, the pressure has been measured across phases X and Z and the current in line Y, so that the current curve is 90° out of its correct phase. The maximum value of the current-rush is over 90 times the steady magnetizing current shown after 2 minutes. In this case the switching occurred very near the zero point on the pressure wave, i.e. at the instant at which under steady working conditions the flux density should have a positive or negative maximum. Allowing for phase displacement of the current curve the pressure is decreasing (B, Fig. 2) and the flux should have been a positive maximum. Assuming, in the first instance, that there is no remanent magnetism in the core, it follows that at the end of a quarter-period, when the "steady condition flux" would have been zero, the flux will now be $-N$ (if N is the maximum value of the flux through the core); it is necessary, therefore, that there shall be a negative current. During the first quarter-period the current will not be very large. During the second quarter-period after switching-in, the negative flux through the core must continue to increase in order to provide a counter E.M.F. in the right direction, and at the end of the half-period it will have increased to a maximum value of nearly $-2N$ (neglecting the effects of hysteresis and the resistance of the coils). The current required to produce this negative flux should also reach a maximum value at the same instant.

Had there actually been no remanent magnetism

the current should have continued to remain negative during the third and fourth quarter-periods, but in the curves shown in Fig. 1 the current reverses very soon after the maximum point on the pressure wave, so that there must have been a considerable positive remanent magnetization of the core at the instant of switching-in, i.e. conditions were not as bad as they might have been.

During the third quarter-period after switching-in, therefore, the flux changes from negative to positive

(Current 90° out of correct phase.)

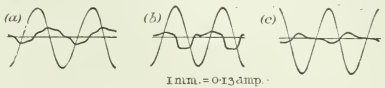
FIG. 3.—Switch-in of 3 × 100 kw. Three-Phase Mesh Transformers, 50 periods, 6,600 volts.

and the current required to produce it does the same, but, since the positive flux is comparatively small, the current required to produce it is small also, and the positive current during this and the fourth quarter-period is relatively small. The iron in this state being in a condition in which it has a very high permeability, it follows that a comparatively small increase in current is required to produce the necessary change of flux through the core. The curve of current is almost square, and the value of the current up to the bend represents the magnetizing force necessary to reverse the direction of magnetization of the iron, the subsequent alteration of flux being effected by a very small change in the current. The part of the curve marked C B is therefore a measure of the coercive force for the iron required to reduce the magnetism to zero. It is interesting to note that this coercive force increases during the first ten or twelve periods, due presumably to the repeated powerful negative magnetization of the iron.

In this discussion the effect of eddy currents has necessarily been omitted. The chief effect of the additional loss due to them will be to introduce a component into the current curve in phase with the voltage, this bringing the resultant current-wave more closely into phase with the voltage than the flux curve. This is shown in Fig. 1, and the eddy-current component is clearly considerable. It is interesting to notice how slowly this remanent magnetism dies away. At the end of 50 seconds it is strong, and even after two minutes it is appreciable. This result, of course, is in accordance with the well-known fact that in order to destroy remanent magnetism it is necessary to demagnetize the iron by a magnetizing force continuously reversed and considerably stronger than that which produced the original magnetization. With the currents used, the magnetizing forces are not powerful enough to effect the demagnetization of the iron rapidly. It has sometimes been noticed after switching in transformers that the pronounced hum which always accompanies excessive magnetization may last for as long as half an hour. During this time the heating of the core due to eddy currents and hysteresis is considerably greater than it is under steady conditions, and under some circumstances this may give rise to trouble in operating the transformer.

Another switch-in is shown in Fig. 3, in which the instant of closing circuit is very near to the time of maximum potential difference, and in which the current-rush is negligible. The remanent magnetism in this case cannot have been large, and the magnetizing current soon settles down to its steady value.

One of the most interesting phenomena in connection with these transformers is the remarkable difference



(Current 90° out of correct phase.)

FIG. 4.—Magnetizing Current of 3 × 100 kw. Three-Phase Mesh Transformers, 50 periods, 6,600 volts.

there is in the wave-shape of the magnetizing current at different times (see Fig. 4).* In Fig. 4 (*a*) the curve is very nearly symmetrical and the core may be assumed to be in a condition in which it is almost completely demagnetized. The two successive half-waves of current are not exactly similar but show "skew" symmetry, a result due to hysteresis in the iron. The curve has

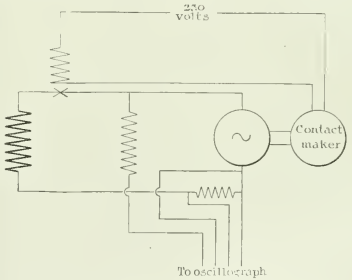


FIG. 5.—Diagram of Circuit for Contact Maker.

a strong fifth harmonic and also a seventh harmonic, while the skew symmetry indicates the presence of even harmonics.

Fig. 4 (*b*) shows a curve also asymmetrical in which the core must evidently have been magnetized. In this case there is a strong fifth harmonic in the current curve. The conditions of the test at the substation were precisely the same as in Fig. 4 (*a*), though the load conditions at the substation were different and the pressure wave therefore slightly different in shape. This difference, however, is hardly perceptible on the pressure wave. In Fig. 4 (*c*) is shown a nearly symmetrical wave (corresponding therefore to a nearly

* Phenomena similar to this have been discussed recently by Mr. L. N. Robinson, *Proceedings of the American Institute of Electrical Engineers*, 1917, vol. 36, p. 989.

demagnetized core) with small harmonics of current. These differences are interesting scientifically as they show the varying conditions of magnetization of the iron core in a transformer working under apparently steady conditions. As suggested above, the variations in the magnetization of the iron may affect considerably the heating of the core.

The factors affecting the current-rush are: (1) the condition of magnetization of the core at the instant

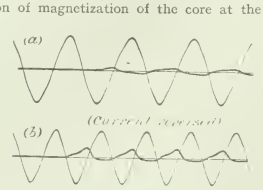


FIG. 6.—Switch-in of two 3-kw. Transformers built for 100 periods.

of "switching-in," and (2) the instant of closing the circuit. It is therefore impossible to control the "rush" unless the transformer is switched out of circuit at a predetermined point on the pressure wave so as to leave a definite remanent magnetism in the core, and is then switched in again at another predetermined instant.

In Figs. 6 and 7 are shown curves obtained for the switching-in of two small transformers, in which the instant of closing circuit was controlled to within 1/1,000th of a second by a switch operated by a contact-maker on the alternator supplying the system. A diagram of the connections used in these tests is shown in Fig. 5. Similar results have been given by Professor J. T. Morris for a circuit in which the connections were closed and opened in rapid succession.

Experiments were first made with a pair of 3-kw. transformers with coupled high-tension circuits designed for a flux density of 3,000 lines per square centimetre at 100 volts and 100 periods. This transformer was connected to a 100-volt 50-period circuit, so that the flux density in the core would be about 6,000 lines per square centimetre.

Two typical curves are shown in Fig. 6, in which (*a*) the circuit is closed at the maximum point in the pressure curve, and the other (*b*) when it is closed at the zero point In Fig. 6 (*b*) the effects are the same as those already discussed, but the conditions more rapidly become steady on account of the smaller size of the transformers. With these transformers when the circuit is closed near the maximum point of the pressure wave the rush is negligible [Fig. 6 (*a*)]—the actual instant of the switch-in was about 0·6 of the half wave from the zero point—and the current at once reached its steady value and did not vary appreciably during the first few seconds, the curve being quite symmetrical.

For purposes of comparison a 10-kw. 200-volt 50-period transformer was tried, designed for a flux density of about 10,000 lines per square centimetre. In Fig. 7 (*a*) is shown the switching-off curve of the magnetizing current of this transformer. In this record the switch-off has taken place at the zero point on the pressure wave (i.e. at the instant at which the flux is a maximum); a considerable remanent magnetism may therefore be expected. In Fig. 7 (*b*) is shown a current-rush when the circuit is closed at the zero point on the pressure curve immediately afterwards. In this case the remanent magnetism was of the opposite sign to that which should have existed at this instant in order to correspond with steady conditions; the rush of current would therefore have to be sufficient to produce a flux nearly three times the normal maximum flux at the end of a half-period. This current rapidly dies away showing that the core soon reaches steady conditions. At the end of 50 periods the current is nearly normal and the wave quite symmetrical.

In Fig. 7 (*c*) is shown another record in which the circuit has also been closed at zero potential difference. In this case there is no appreciable rush of current and the remanent magnetism in the core must have corresponded to steady conditions. Many other records have been obtained which confirm the general character of these results.

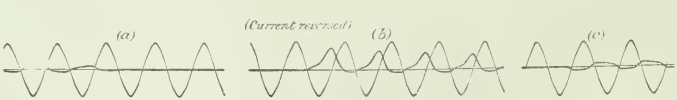


FIG. 7.—Switch-off and Switch-in of 10-kw. Transformer, 200 volts (50 periods).

CURRENT-RUSH ON SWITCHING-IN INDUCTION MOTORS.

A current-rush nearly always occurs when an induction motor is switched on to a circuit. This curve, however, is somewhat different from that of the transformer, since the rotor circuit is closed so that the machine is similar to a short-circuited transformer, whereas in the case already considered the transformer secondary circuit is open. A number of induction motor-generators are in use on the Liverpool Corporation electric supply system, and some tests were made on one of 300 horse-power coupled to a continuous-current generator of 220 kw. output. The motor was three-phase, star-wound, with 6,000 volts between the lines and taking a current at full load of 26 amperes

per phase; the frequency was 50 periods and the speed 420 r.p.m.

No attempt has been made to control the instant of closing circuit, and in this case it will not greatly affect the rush of current. The records show that the rush is extremely large. In these tests it reached a maximum value of over 380 amperes per phase, or nearly 270 amperes R.M.S., i.e. 10 times the full-load current. The pressure wave remains quite steady, since the overload is not large enough to produce an appreciable effect at the end of the feeder from Lister-drive. It is easy to see why this rush is a big one. When the machine is being run up on the continuous-current side, and before the high-tension switch on the induction motor is closed, there is no magnetization in the stator core of the induction motor. If the machine were running absolutely synchronously the conditions would be similar to those existing when a transformer is switched on, and there might be a rush due to the same causes as those discussed above.

This rush will, however, be relatively small, since the flux density in the iron circuit of induction motors is low and there is an air-gap in the iron circuit. Even under the most unfavourable conditions it is not comparable with that found in a stationary transformer.

It is, however, difficult to synchronize these machines exactly; ordinarily, they are switched in when they are running a little above or below synchronous speed. Consequently, there is a sudden rush of current such as would occur in a short-circuited transformer when switched on to a supply circuit on its primary side. In this case the rush on the primary induces a current through the rotor, which almost instantly pulls the rotor into step and which soon dies down to its normal value. This current is of course a load current and involves a large expenditure of power in the motor, so that the forces that come into play are very large. These forces exert very heavy stresses on the induction-motor windings and may easily lead to a breakdown, especially with large machines. The same effect has of course been observed with turbo-generators, in which machines the end windings are now very carefully stayed so as to prevent damage. [It is interesting to compare these rushes with those observed on a 1,500-kw. self-synchronizing rotary converter given at the end of this paper. It is, however, much easier to synchronize a rotary converter or synchronous motor run up on the alternating-current side than a motor-generator of this type run up on the continuous-current side, and then connected direct to the line.] Two records are shown in Fig. 8. In one of these, Fig. 8 (*a*), the motor was switched in without great care being taken in synchronizing it; the maximum current-rush is nearly 10 times the full-load current. In the other case great care was taken to bring the speed of the induction motor-generator to exactly its running value before the switch was closed. The initial rush is nearly the same, as far as it can be estimated from the curve, but the current dies down much more quickly to its steady value under these conditions.

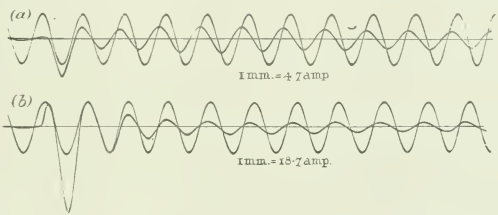


FIG. 8.—Switch-in of 300-h.p. Squirrel-Cage Induction Motor, Three-Phase Mesh, 6,000 volts, 420 r.p.m.

CURRENT-RUSH ON SWITCHING-IN UNDERGROUND CABLES AND CONDENSERS.

When high-tension transmission lines and cables of great length were first installed the rise in pressure, and still more the rush of current to the cable which was liable to occur when the cable was first switched in, were hardly appreciated. Later on, cable-charging devices were often employed in which the cable was connected first through a high resistance, usually a water resistance, and then direct to the line in order to avoid pressure-rises. These devices are not a complete protection, since a rise in pressure may occur whenever the load on the system is changed suddenly; nowadays a large factor of safety is used in the design of cables and insulators and such devices have become less necessary.

In most circuits in this country long lengths of underground cable are used, which have a comparatively small inductance, and the effects observed closely resemble what happens when a condenser is suddenly switched on to an inductive circuit.

The case of an unloaded feeder may first be considered. This is usually switched on by connecting it through a transformer to a number of generators. The transformer has, of course, considerable inductance due to magnetic leakage, and the generators also possess inductance, so that the conditions existing may be represented by an inductive circuit which is suddenly connected to a condenser. The conditions may be

reproduced in the laboratory by switching a number of condensers on to an alternator.

In order to demonstrate the effects which may be expected under such conditions, a number of records have been made of the current and potential difference on a condenser at the instant of closing circuit.

In this case a 30-kw. 200-volt 50-period alternator was connected to a condenser having a capacity of about 15 microfarads. The steady current flowing through the circuit is shown in Fig. 9 (*a*). A high-frequency ripple is strongly marked, and it is interesting to compare this record with that of the charging current flowing into a cable about 3 miles long (capacity 1 mfd. from core to sheath) from Lister-drive central station which gives an almost perfect sine wave. In Fig. 9 (*a*) there is a strong 19th harmonic, while in the wave of charging current to the cable is a strong 25th harmonic. With the condenser the instant of switching in was controlled by a switch and contact maker as already explained. The curves of current and pressure for the two extreme cases (i.e. switching in at maximum pressure and zero pressure) are shown in Fig. 9 (*a*) and (*b*). In Fig. 9 (*a*) a strong current oscillation is observ-

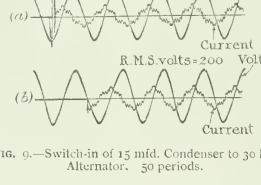


FIG. 9.—Switch-in of 15 mfd. Condenser to 30 kw. Alternator. 50 periods.

able with a frequency of about 800 periods per second, the maximum value of the current being nearly double that flowing under steady conditions. There is very little change in the pressure wave except for a sharp indentation at the instant when the surge occurs, the whole surge being over in a comparatively short time.

There are clearly three possible conditions of circuit which will produce varying results at the instant of closing circuit, namely:—

(1) That in which the values of the capacity and inductance are such as correspond to a natural frequency higher than the working frequency [this is the case illustrated in Fig. 9 (*a*)];

(2) That in which the natural frequency corresponds to the working frequency (the resonant case); and

(3) That in which the natural frequency is lower than the working frequency.

There is also a fourth case, i.e. when the resistance of the circuit is so high that the circuit is non-oscillatory.

The only case where there is any serious danger is the first, and of course the condition of high natural frequency is much the most common. The theory of these surges has been fully worked out by Steinmetz and others, and it is unnecessary to deal with it here.*

* See Appendix.

We may regard the current flowing in the circuit as due to a combination of the currents due to the surge which arises when the circuit is closed and the current that will flow under steady conditions. The surge depends upon the instant at which the switch is closed. Theoretically, it will, in most cases, be greatest when the switch is closed at the instant of maximum potential difference. This is clearly shown experimentally in Fig. 9 (*a*) and (*b*). The surge rapidly dies away, the decrement being controlled by $R/2L$, the ordinary decrement factor in an oscillatory circuit. In a transmission line the surge would of course travel along the line as a space wave, and be reflected back at points where the line constants change. The steep-fronted surge corresponds to the high-frequency oscillations described above, the surge being less steep-fronted the lower the frequency of the natural oscillations. In a transmission line only a portion of the total capacity

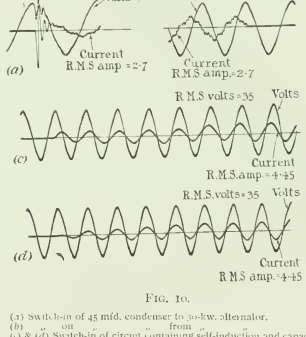


FIG. 10.

(*a*) Switch-in of 45 mfd. condenser to 30-kw. alternator.
(*b*) " out " " " " "
(*c*) & (*d*) Switch-in of circuit containing self-induction and capacity adjusted for resonance.

and inductance must be taken into account in determining the natural frequency of the oscillation.*

In order to illustrate these effects more fully, tests were made in the laboratory with a condenser of 45 mfd. capacity. In these tests [see Fig. 10 (*a*)] the natural frequency of the condenser and machine was found to be 12 times the frequency of the system. From the equation given in the Appendix the maximum value of the current-rush should also be approximately 12 times the normal current flowing into the condenser when the circuit is closed at maximum potential difference. The actual maximum rush in this case is about 9 times the maximum value of the steady charging current.

The pressure-rise is more marked in this record than in the ones in Fig. 9, as the oscillograph has been able to respond more closely to the lower-frequency oscillations; and although the maximum pressure on the

* C. P. STEINMETZ: "Transient Phenomena."

condenser or cables is not double the steady peak value, it shows a rise of over 30 per cent above the peak. In the Appendix it is shown that the maximum pressure-rise possible is nearly twice the maximum or peak value of the potential difference. This agrees fairly closely with the pressure-rise recorded by Mr. Duddell of 2·6 times the R.M.S. value. The switch-off [Fig. 10 (*b*)] shows no remarkable results. The circuit was then adjusted by inserting additional inductance until resonance was obtained. The curves of switching in

In Fig. 11 (*b*) is shown a switch-in which occurred near the instant of maximum potential difference. In this case also the surge is almost inappreciable on the record, probably due to its high frequency. The most interesting records have been obtained when the feeder is switched off. The charge on the cable does not die away continuously, but there is a low-frequency oscillation—in this case of about 12 periods per second. The instrument transformers remained connected after the cable was switched off and the frequency observed

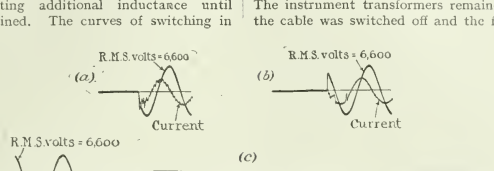


FIG. 11.

(*a*) & (*b*) Switch-in of 3½ miles of 6,600-volt three-phase cable.
(*c*) " off " " " " " with instrument transformers connected.

at maximum and zero points on the P.D. wave are shown in Fig. 10 (*c*) and (*d*). Fig. 10 (*c*) shows a switch-in at the maximum point on the wave of potential difference, and Fig. 10 (*d*) the corresponding switch-in at the zero point on the wave of potential difference. All high-frequency oscillations have, of course, disappeared, and the current rises gradually

corresponds to the natural frequency due to the instrument (volt) transformers and the cable, in series. The natural frequency of the circuit with instrument transformers only in circuit is of course much lower than that when the cables are switched on to the busbars. The inductance of the primary of a voltage transformer is high, such a transformer being equivalent to a choking

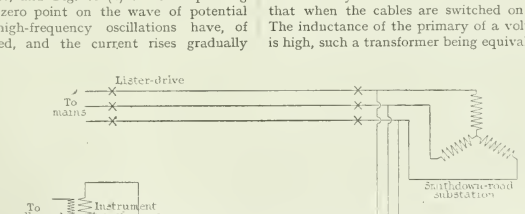


FIG. 12.—Arrangement for observing Pressure at end of Feeder.

to the full value. The exponential terms can be calculated from the equations given in the Appendix.

In the feeder-switching experiments the length of cable used was 3½ miles, and was designed for 6,600 volts between the three cores, with a capacity between each phase and earth of 0·27 mfd. per mile. Each core had a cross-section of 0·2 sq. in. and the outer sheathing was earthed. A switching-in curve is shown in Fig. 11 (*a*). The surge is very small and the conditions steady down after an extremely short interval.

coil of large inductance. There is at this end no appreciable pressure-rise at the instant of switching off, though in many cases, under suitable conditions, there is a probability of its occurring.

Tests were also made in which the cable was switched off at the substation and the pressure at the central station observed. In this case the feeder switches at the central station were open, and the feeder was supplied with current from the substation, which of course was supplied with power from the central station

through another feeder. The arrangements are shown diagrammatically in Fig. 12. Two of these records are given in Fig. 13, one corresponding to a switch-in and the other to a switch-off near zero current. The instant of opening circuit could not, of course, be controlled in this case, but, as in most cases where oil-break switches are used, the circuit is opented at the instant of zero current. There is no appreciable pressure-rise in either case, and little or no evidence of pressure-surge.

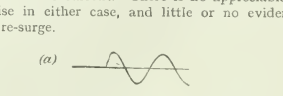
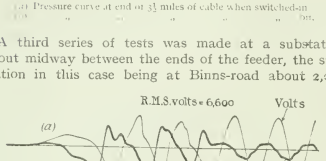


FIG. 13.

(a) Pressure curve at end of 3½ miles of cable when switched-in
(b) " " " " " " off.

A third series of tests was made at a substation about midway between the ends of the feeder, the substation in this case being at Binns-road about 2,000



(Current 90° out of correct phase in (*a*)).

FIG. 14.

(a) Switch-in of transformer (3 × 100 kw.) at substation by switch at central station through 2,000 yards of high-tension cable.
(b) Switch-off of transformer (3 × 100 kw.) at substation by switch at central station through 2,000 yards of high-tension cable.

yards from Lister-drive and the feeder one running from Lister-drive to Smithdown-road, a total distance of 5,250 yards. The current was switched off at Lister-drive and the record taken at Binns-road. In this case the transformers at the substation were left connected to the feeder, and as in all cases the pressure and currents were recorded by means of the instrument transformers. These records are shown in Fig. 14. The switch-in [Fig. 14 (*a*)] presents no marked peculiarities except for irregularities due to switch contact and a small current-rush, but the switch-off [Fig. 14 (*b*)] shows a considerable rise in pressure, the maximum value of the pressure being 11,400 volts, i.e. nearly 25 per cent in excess of the maximum pressure due to the ordinary potential difference. The switch begins to break circuit for three half waves and finally opens circuit at the third wave. There is a slight current surge just before the circuit is opened, due to the partial break and subsequent closing of the circuit. The position of Binns-road is nearly midway between Lister-drive and Smithdown-road, and would therefore correspond to an anti-node of pressure in the cable, i.e. with a reinforcement of the outgoing surge from Lister-drive by the reflected portion at Smithdown-road. The pressure-rise in this case, however, is probably due to the effect of switching off the transformer and is caused by its inductance; the pressure rise is cut down by the capacity of the cable shunted across it, but the capacity is not large enough to do this completely. In this case the method of switching off employed, i.e. opening circuit at the central station, reduces the strain on the transformer, but increases the strain on the cable, whereas switching-off at the substation may increase the strain on the transformer but protects the cable from excessive pressure.

Paralleling of Alternators.

The transient currents which flow when alternators are switched into parallel are well known, and the theory of parallel running has been fully developed by Rosenberg, Everest, and others. A few oscillograms, however, have been taken of the currents which flow between turbo-alternators when a 6-pole 1,500-kw. machine is paralleled with a 6,000-kw. machine having four poles. The pressure waves of these machines are very nearly pure sine curves as shown in Fig. 15. the most remarkable feature being the irregular shape of the wave of the current.

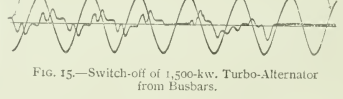


FIG. 15.—Switch-off of 1,500-kw. Turbo-Alternator from Busbars.

It was shown in a paper by Mr. Catterson-Smith and the author that the reactance of three-phase alternators to currents of triple frequency is very small compared with that offered to the main-frequency current. Consequently, the component of the current circulating between two machines, even when the pressure wave has very small harmonics, will be likely to contain a strong third harmonic of current if all neutral points are earthed. At Lister-drive the neutral point of only one machine is earthed, and there are therefore no triple-frequency currents shown in Fig. 15. In this curve a very strong fifth harmonic of current is present. The records show the switch-off and emphasize the fact that it takes two or three periods to open a circuit with the heavy gear required for controlling 1,500 kilowatts. This operation is shown at the end of the record.

The current which flows when the machine is paralleled depends upon two factors, i.e. the phase relationship between the E.M.F. of the incoming machine and the busbar pressure and the exact relative speed of the machines at the instant of closing circuit. Though paralleling is an operation which, in the hands of a skilful switchboard attendant, can be effected with certainty, very nearly at the same phase instant, there may be variations of as much as 1/20th of a period in

FIG. 16.—"Paralleling" 1,500-kw. Turbo-Alternator with 6,000-kw. Turbo-Alternator running at about ¾ full load.

the time of closing circuit. This variation of course produces considerable differences in the currents which flow between the incoming machine and the busbar. These are shown in Fig. 16. In Fig. 16 (*a*) the switch has been closed almost exactly at the right moment and the current-rush is very small, there being very little phase-swing. In Fig. 16 (*b*) there is a considerably greater phase swing. These two curves represent probably the limits of variation which may occur under ordinary working conditions with a good switchboard attendant. In Fig. 16 (*b*) it will be noticed that there is a more or less regular period of increase and decrease in current. The period of this variation in current is approximately four-fifths of a second and represents the natural period of swing of the alternator when running in parallel with a number of other machines. The curve shows the variation in phase difference between the circulating current and the pressure of the machine. After the instant of closing circuit in Fig. 16 (*b*) there is an irregular current surge which dies down rapidly, and after about 7 periods there is almost exact phase opposition between current and potential difference. This current, which is a motoring current for the machine, increases to a maximum and then dies almost completely away except for a strong fifth harmonic which still continues to flow round the circuit. During the next 10 periods the current circulating increases steadily, but it is now a generated or load current, being nearly in phase with the potential difference. It again falls to a minimum at the end of about 20 periods from the previous minimum, and the process is repeated. The maximum value of the current during the second maximum period is perceptibly smaller than it is during the first. The natural period of swing of the machine can of course be calculated from the moment of inertia, the short-circuit curves corresponding to a known pressure, and the number of poles on the generator. The experimental result is, however, interesting and gives a definite figure under actual working conditions. It is, of course, important, in order to avoid hunting, that this period is not the same as that at which the governing mechanism operates.

A similar test was taken for a 1,500-kw. self-synchronizing rotary converter, the record from which is shown in Fig. 17. In this case the period of swing is shorter, about six periods between minimum and maximum motoring currents. This, of course, is what is to be expected, since the moment of inertia of the revolving mass is very much less than in a turbo-generator of the same capacity. The decrement of the swing also is much greater, the phasing current during the second phase-swing being much less than that of the current during the first phase-swing. This machine was fitted with copper dampers on the poles which greatly increase the damping of the oscillations. The maximum phase-swing current occurs at the time when the current and pressure are nearly 90 degrees out of phase, the first maximum current occurring when the current and pressure are 180 degrees out of phase. This current rapidly falls to a minimum, then rises and gives a maximum about five or six periods after the first minimum. As in the case of the turbo-alternators the wave

shape at the points where the current is a minimum becomes very irregular, there being in this case also a strong fifth harmonic. The same harmonic shows strongly in the steady current curve for the rotary converter when running light, and is probably due to the iron of the transformer or to a tooth ripple in the converter itself.

The author wishes to record his indebtedness to Mr. H. Dickinson, City Electrical Engineer to the Liverpool Corporation, to Mr. Robinson and Mr. Breach, the assistant engineers, and to Mr. Hamilton the engineer-in-charge at Lister-drive, for their help and co-operation in carrying out the tests at the various stations and substations where the work has been done.

Substituting measured values, $x_c = 212$ with 15 mfd. in circuit,

$r = 0{\cdot}6$ ohm (including leads),

$x = 0{\cdot}55$ ohm (mean value for four positions of the rotor),

the value of $\sqrt{(x_c/x)}$ is therefore 20 approximately.

The maximum current flowing due to the high-frequency oscillation calculated from formula (1) is very nearly 19 times the steady current, the exponential term in the formula given above reducing the maximum value by about 5 per cent.

The maximum potential difference on the condenser calculated from formula (2) occurs at the end of half a period of high-frequency oscillation and is very nearly 1·9 times E.

When the switch is closed at zero potential difference, i.e. when $\theta_0 = \pi/2$ the maximum high-frequency current at the instant of closing the circuit is nearly twice the steady current.

The maximum potential difference is hardly affected, since the exponential term in the formula is very small indeed.

The worst possible case of pressure-rise occurs when the switch is closed at maximum potential difference, and the natural damping in the circuit is small.

Neglecting the exponential term it is 2 E, where E is the maximum pressure given by the alternator.

It has not been possible to record pressure-rises of this magnitude in the case of actual cables, on account of the very high natural frequency of such systems. The pressure on the cable may, however, usually be expected to approximate to this value if the circuit happens to be closed at the maximum point on the wave of potential difference.

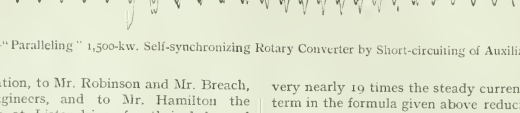


FIG. 17.—"Paralleling" 1,500-kw. Self-synchronizing Rotary Converter by Short-circuiting of Auxiliary Motor.

APPENDIX.

The equations given by Steinmetz* for the current flowing at any time when a condenser is switched on to a circuit having inductance and resistance and when the condensive reactance is large in comparison with the inductive reactance of the circuit, are as follows:—

$$i = -\frac{E}{x_c}\left\{\sin(\theta-\theta_0) + \varepsilon^{-r\theta/2x}\left[\sin\theta_0\cos\sqrt{\frac{x_c}{x}}\theta - \sqrt{\frac{x_c}{x}}\cos\theta_0\sin\sqrt{\frac{x_c}{x}}\theta\right]\right\}$$

The potential difference at the condenser terminals is

$$e = E\left\{\cos(\theta-\theta_0) - \varepsilon^{-r\theta/2x}\left[\cos\theta_0\cos\sqrt{\frac{x_c}{x}}\theta + \left(\frac{r}{2\sqrt{(x\,x_c)}}\cos\theta_0 - \sqrt{\frac{x_c}{x}}\sin\theta_0\right)\sin\sqrt{\frac{x_c}{x}}\theta\right]\right\}$$

where r is the resistance of the circuit in ohms;

$x = 2\pi f L$ = the reactance in ohms due to the self-induction L of the circuit when a current of frequency f periods per second is flowing;

$x_c = 1/(2\pi f c)$ = the condensive reactance in ohms due to the capacity C measured in farads;

$\theta = 2\pi f t$;

and the electromotive force at the instance of closing the circuit is represented by $E\cos\theta_0$.

In these equations it is assumed that $r^2 < 4\,x\,x_c$, so that the circuit is an oscillatory one, and that x_c is large compared with x, so that, under steady conditions, the current is leading by nearly 90 degrees, which corresponds to the conditions prevailing in the tests described on switching in condensers.

If the switch-in is at the maximum pressure on the alternator, $\theta_0 = 0$.

* C. P. STEINMETZ: "Transient Phenomena" (page 97).

The maximum potential difference is very nearly 2 E.

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Discussion before The Institution, 23 May, 1918.

Professor J. A. Fleming: In the brief bibliography which the author gives at the end of his paper he does not suggest quite so fully as perhaps might be done that this subject has a considerably longer history than his references would suggest. In Volume 21 of the *Journal* there is a paper entitled "Researches on Alternate-current Transformers," which I read before this Institution 26 years ago. In that paper I was the first to describe and explain these current-rushes in transformers. At that time we were beginning to be educated in alternating currents. Dr. Ferranti had just completed laying the long trunk mains for the London Electric Supply Corporation from Deptford to London, and I was much interested in examining some of the phenomena. Those mains were at first switched on to and off the busbars at the station without regard to the capacity and inductance effects, and the result was that we had to gather a good deal of experience in a somewhat expensive way. Amongst other things the question of current-rushes into transformers attracted my attention. There were mysterious failures of transformers at the moment of switching on and off, and one of the first experiments I tried was to put in series with the primary circuit of a transformer an incandescent lamp so chosen that the filament was not more than just red hot with the magnetizing current of the transformer. If the transformer were switched on and off a number of times, every now and again the lamp would flash up, showing a rush of current into the transformer. The experiment was varied by putting a vacuum tube across the secondary of an induction coil, the primary of which was in series with the transformer; if the positions of the primary and secondary coils were then adjusted so that the vacuum tube was just extinguished, when there was a rush of current in the transformer the tube flashed up. Another plan we tried was to put against the transformer a stick provided with discs of wood at the two ends, like a stethoscope. If one end of the stick were pressed against the transformer and the other against the head, on switching on and off one occasionally heard a great thump, which was at the moment the current-rush took place in the transformer. In these experiments I obtained a general knowledge of the reasons for the effect, and I gave in my paper the explanation that it was due to the particular phase of the magnetization which was left in the transformer core when it was last switched off. Then as regards the rushes into the mains, it was very soon evident that these depended on the phase of the electromotive force when the switch was closed, and I gave an elementary theory of the effect in a book which was published about that time by me on the "Alternate Current Transformer." Since that date we have had a large accession to our means of experimenting by the invention of the Duddell oscillograph. There is, however, another instrument which can be used, although perhaps it is not quite so useful as the oscillograph, and that is a Brann cathode-ray vacuum tube. The instrument consists of a long glass tube with a bulb, and at the end there is a phosphorescent disc. By means of an electrostatic machine, or a large number of small secondary

cells, cathode rays are projected along the tube and form a small spot of light on the phosphorescent disc. That flexible conductor can be deflected either electrostatically by plates inside the tube, or magnetically by coils outside it, and by examining the movements of the spot of light in a revolving mirror we can see very easily the effect of the current-rushes into a transformer or a cable. I think that cathode-ray tube is capable of being greatly improved; but at the present moment it is not so easy to use it for photographic purposes. There is one point in the present paper which I should like to have seen expanded, namely, experiments of the kind described but conducted with large switches, especially oil switches. We want to know a great deal more about what happens at the moment of closing and opening switches to obtain ability to control the phase. I have been carrying out some experiments with electric furnaces. I have found we need a great deal more information than we possess at present as to what goes on at a switch on opening and closing the circuits with large alternating currents in them, and not only of knowing what goes on but of being able to control the particular phase in which the circuit is opened. I think that much of the useful application of large currents in electrothermal work will depend on improvements being made in switches which control them. The author's experiments are valuable as a continuation of work along this line of research. I presume that the oscillograms of which he has shown us specimens are actual photographs taken with the oscillograph. Many of them illustrate very well the fact that the current disturbance takes place when the switch is closed, at the instant when the electromotive force is at a maximum; but that when a switch is closed at the instant when the electromotive force is zero, the current settles down to its normal value without any irregularity.

Mr. A. R. Everest: It is shown in the diagrams in the early part of the paper that the potential difference is taken between two lines while the current wave is the current in the third line. Is there not a risk of sometimes getting a misleading result, because it is known that we can have a third harmonic in a phase voltage while it will not show at all between lines? The pressure curve taken between the other two lines is therefore not an indication of the shape of the pressure wave in the phase on which the current is being measured. I do not mean to suggest that this particular test contains any error, but I would ask the author whether he does not think the method of connection is undesirable for general use. Regarding the troubles that arise in these switching operations, I should like to know what the author considers to be the best means of avoiding them. In the case of transformers, what procedure would he recommend to avoid as far as possible leaving the transformer in an undesirable condition? It has been recommended in connection with transformers with rotary converters that the combination should be disconnected bodily from the alternating-current lines, leaving the transformer magnetism to die down as the rotary converter dies down. As regards induction motor surges, I should like to know what the author thinks of the suggestions that have been made at different times for the purpose of avoiding pressure surges on switching-in induction motors, viz. having one terminal of the stator winding connected first to the line, and secondly the suggestion that one phase of the motor circuit should be always left closed before the switching operations take place.

Professor J. T. MacGregor-Morris: First regarding the induction motor tests, the rushes which the author examines appear to be rushes of current. Mr. Everest has just drawn attention to the fact that there are also pressure-rises which, generally speaking, are much more dangerous. I know a case of a fairly large motor in which when it is switched into circuit a spark always passes between the rotor and the stator owing to the rise of pressure. It would be interesting to know whether the author has obtained any results which show such rises. Turning to the question of the current-rush in transformers, Professor Fleming has mentioned that a lamp can be used to show these current-rushes, also a wooden stethoscope, and a vacuum tube. One of the simplest ways of demonstrating it was shown to me by Mr. Clinker at the B.T.H. works many years ago. He used a direct-current ammeter having a central zero, and as those instruments are more robust than they used to be it is safe to switch such an instrument into an alternating-current circuit so that the alternating current passes through the shunt of the direct-current instrument. If we do that several times we get occasionally a big direct-current rush. The ammeter needle swings right over, and then slowly comes back, the alternating-current only being sufficient to make the needle tremble slightly on its pivot. I remember Mr. Clinker showing me the switching on of a 50-kw. transformer, the current-rush sometimes lasting for as much as 30 seconds. That was some 15 years ago. Now, as the author points out, transformers are worked at higher flux densities and lower frequencies, and these effects are very much more marked. I should like to ask him whether he can give us a quantitative idea of the time that this rush will last. I should not be at all surprised to find that in a 500-kw. transformer the rush might last for as much as 10 minutes.

Mr. H. Brazil: It may be of interest if I give some figures from an electrical supply company's system which show the presence of these transients and the causes to which they are due. The apparatus I have used was described in Mr. Patchell's paper before the Institution * and served to indicate when the pressure between any phase and earth rose to more than 50 per cent above the normal, the figure at which the arrester horns were set. I have records of 1,300 discharges extending over a period of 14 years, and give below particulars of the chief causes of these pressure-rises. The most frequent cause was the energizing of the cables by connecting them to the generating plant when at rest, and then running up to synchronous speed. In doing this, one is very likely to run through a particular speed which, combined with the induction and capacity in circuit, will give resonance. This method of energizing cables

* *Journal I.E.E.*, 1905, vol. 36, p. 66.

gave so much trouble that it had to be discontinued. The next cause was the linking in and out of sections of the busbars to which three-phase voltmeter transformers were connected. The self-induction of the transformer, together with the capacity of the cable connecting it to the busbars, was just right for resonance at the working frequency. I had the pleasure of assisting Mr. Duddell in these experiments, and we found that the pressure-rise was done away with by simply connecting the transformer to the busbars with another piece of cable having a different capacity.* Pressure-rises were also due to breakdowns on instrument transformers and short-circuits on machines and cables. On some occasions rats and mice, by bridging across from a live terminal to earth with their bodies, started discharges which gave rise to surges. The variation of speed owing to governors on steam sets not working properly was quite sufficient to cause a rise of pressure, due probably to resonance, at a particular speed. Switching in induction motors was another source of pressure-rises, and this was got over by putting in circuit, at the moment of switching on, a very substantially built choking coil, which by a further movement of the switch was cut out. A matter of considerable interest in connection with minimizing the bad effects of these pressure-rises was that by setting the arrester horns to spark at 30 per cent above normal pressure instead of 50 per cent, although, as was to be expected, the number of discharges in a given period was increased, the number of breakdowns on motor-generators and other apparatus was very materially reduced.

Professor G. W. O. Howe: I intended to refer to the method of showing the current-rush on switching on a transformer by putting a continuous-current ammeter in series with the alternating-current ammeter, but Professor MacGregor-Morris has already done so. It forms a simple laboratory experiment for showing students the phenomenon, and especially for studying its duration; in some cases even with a 5-kw. transformer the effect seems to last one or two minutes; in fact, the continuous current ammeter seems sometimes to settle down to a small reading for a long time afterwards. On page 447 the author says: "During the third quarter-period after switching-in, the flux changes from negative to positive and the current required to produce it does the same." The reversals of flux and current will not occur at the same moment, however. On account of hysteresis the former will occur after the latter. A little lower down he says: "The iron in this state being in a condition in which it has a very high permeability, it follows that a comparatively small increase in current is required to produce the necessary change of flux through the core." I think that it would be more correct to say that the value of dB/dH is very high, since it is not the ratio of B to H that is important but the value of dB/dH. One can hardly say that the iron has a high permeability in that region, since the value of B/H passes through zero. On page 447 I notice the author says that in Fig. 4 (*a*) the curve is very nearly symmetrical and that the core may be assumed to be in a condition in which it is almost completely demagnetized, and he goes on to say: "The two successive half-waves of current are not exactly similar but show 'skew' symmetry, a result due to hysteresis in the iron." From his subsequent statement that it indicates the presence of even harmonics, it appears that by "skew" symmetry he means that the two half-waves are not similar but that what happens at the beginning of one half-wave happens at the end of the succeeding half-wave. I think I am right in saying that this cannot be due to hysteresis, apart from unsymmetrical magnetization. If we have symmetrical hysteresis, I think we shall not get any even harmonic. The fact that we get an even harmonic shows that the iron was not completely demagnetized. With regard to the possibility of controlling the current-rush and its duration, it is interesting to consider why the dissymmetry dies away. I should like to ask the author whether he has gone into the point why the dissymmetrical current gradually becomes symmetrical. I think it may be due to greater pressure drop in one direction than in the other. In one direction we have a very large current and therefore a large pressure drop, and in the other direction a small pressure drop, so that the transformer has to develop a smaller electromotive force in one direction than in the other, and I think that this may tend to restore the symmetry. If so, it rather suggests that one way of getting over the trouble is to insert in series with the transformer a resistance which can be switched out very rapidly. I do not know that it is desirable to go to any trouble to control this rush, but I think that it could be greatly reduced if necessary. With regard to switching in the induction motor, illustrated in Fig. 8, the author draws attention to the fact—but I do not think he offers any explanation—that the amplitudes of the current-rushes in Figs. 8 (*a*) and 8 (*b*) are about the same, and that it is only the durations that differ. The rotor being closed in these two cases, I presume that the rotor winding, being a closed copper circuit, acts as a screen to the magnetic flux when we first switch on, and that on account of the currents induced in the rotor, the magnetic flux is driven along the leakage paths and prevented from entering the rotor. As the result of this screening action one gets just the same rush initially whether the rotor is running synchronously or non-synchronously; but the current quickly falls to the value corresponding to the slip at the moment, and then changes slowly to its steady value as the rotor is brought up to its normal speed. I think that this is the correct explanation of the amplitude of the rush being the same in the two cases. There is one point to which I have drawn attention on a previous occasion. In Fig. 9 (*a*) the author says there is a strong 19th harmonic, while in the wave of charging current to the cable there is a strong 25th harmonic. The numbers attached to these harmonics are rather uncertain. I suppose that the number of teeth in the alternator is such that one would expect the ripple to have a frequency 18 times the frequency of the fundamental, and therefore if one enlarges the oscillograph record to a suitable scale and measures the time elapsing between two of those ripples we shall find it to be $\frac{1}{18}$ of the period, or, in the case of the Lister-

* *Journal I.E.E.*, 1914, vol. 52, p. 1.

drive station, $\frac{1}{24}$ of the period. Every half-period of the main wave the phase of the ripple reverses, thus preserving the symmetry of the curve and excluding an even harmonic. If we analyse it we find that the 18th ripple may be resolved into the 17th and 19th harmonics, and we get a slightly larger condenser current from the 19th than from the 17th on account of the higher frequency. Apart from this I think that there is no reason for favouring the 19th rather than the 17th harmonic when referring to the ripple.

Mr. F. Purser-Fletcher: Many years ago I experienced a great deal of trouble with current surges; this occurred generally in connection with the switching-in of large induction motors, and the late Mr. Duddell made oscillograph tests to see what could be done to prevent or reduce them. In addition to large current-rushes, extreme pressure-rises were obtained, damaging the first coils of the stator windings. In another case the pressure-rises on the feeders were so great that it was sometimes not possible to use all the feeders connecting the different substations at one time, due to their large capacity causing resonance, and the periodicity at the main generating station had to be reduced and the alternators run with the strongest excitation. The conditions in those days were not so well understood, and I feel now that such matters being discussed and examined more carefully will give the operating engineer a better opportunity of understanding and avoiding some of the difficulties we have had in the past.

Mr. H. W. Taylor: It is interesting to notice that many of the cases of current surges are particular examples of an alternating-current circuit in mutual induction with another circuit, and that the short-circuiting of alternators, the switching in of induction motors, the paralleling of alternators as shown in Fig 16, and the record in Fig. 17 of a self-synchronizing rotary converter, are all similar phenomena. With reference to Fig. 17, I would suggest that a better term than paralleling might be used, as the actual paralleling occurs at a time previous to the taking of this film, when the rotor of the machine is locking into step. Fig. 17 really shows what happens when a reactance (namely the starting motor) is eliminated from the circuit. With regard to alternators, we are nowadays able to eliminate the stresses due to these surges by the introduction of considerable reactance in the winding. Unfortunately, however, this method cannot be applied to the ordinary induction motor, owing to the necessity of keeping the power factor high. With reference to Fig. 11, which shows a low-frequency surge in the line itself after the switch is opened, it is perhaps fortunate that in some cases the stored electromagnetic and electrostatic energy can be dissipated in this way. In cases where the electric constants of the circuit are not so related as to give rise to a surge, the whole of the stored energy in the circuit has to be dissipated at the contacts of the switch, in the same way as the stored energy in the field of the machine has to be dissipated in the arc formed at the contacts of the field switch when a discharge resistance is not in use. A consideration of this matter may explain breakdowns which sometimes occur in switching, especially on low-voltage circuits; such circuits are liable to be of low power factor and therefore to contain a large store of energy, and the switches, although mechanically sound, may not be designed to withstand the electrical stresses which may occur at the terminals, when the switch is opened. The reference in Fig. 15 to the irregular shape of the current wave circulating between two machines suggests that undesirable generator harmonics may be eliminated from the system by running the generator in parallel with dissimilar machines; in fact, in big systems it is found that harmonics in the voltage wave of the system are absent for this reason. It is well known that third harmonics frequently appear between line and neutral, although they rarely occur between the lines themselves. In a recent case a third harmonic between line and neutral gave rise to interference in a neighbouring wireless station, but the trouble was sufficiently eliminated when two machines were run in parallel with their neutrals connected through an earthing resistance.

Mr. C. H. Wordingham: I should like to make one personal remark in connection with the paper, because it recalls to my memory an incident of 25 years ago. Both the author and Professor Fleming have referred to the early experiments on current-rushes. At the time they were made I was on the staff of the London Electric Supply Corporation, and as a matter of fact it was I who first noticed this phenomenon in connection with the switching on of some transformers under test, and I remember suggesting at the time that it might be due to the state in which the iron was left on switching off. The matter was referred to Professor Fleming, who was then advising the company, with the result, of course, that we got a full and complete explanation. I vividly remember the experiments, because the current-rush was so violent that the transformer actually jumped. I also remember the experiment of the lamp flashing up and the tremendous current-rush through the ammeter.

Professor D. Robertson (*communicated*): In connection with Fig. 1 it would be of interest if the author would give the ratio of the current-rush to the full-load current, as well as to the normal magnetizing current, and would also indicate how the transformers were connected during the test. On switching in a three-phase transformer (or bank of transformers) so that contact is made at the zero of voltage for one phase, the voltages of the other phases will be $\frac{1}{12}$ of a period before and after their maximum values; thus these phases will start under easier conditions and will have a much smaller current-rush than the first. If the transformer be mesh-connected, the line current taken by the oscillograph is the resultant of the currents in two phases, of which one has only a moderate current-rush. That in the other must consequently be much greater than the oscillograph indicates. On the other hand, if the transformers be star-connected, although the oscillograph does show the actual current, that current is considerably reduced by the unbalancing of the voltages caused by the fact that the same current must also split up between the other two phases. Thus,

for an oscillograph in the line to show the worst conditions that could arise, the primary must be star-connected and its neutral be connected to that of the supply. Can the author say whether in his test the oscillograph was in the line which carried the greatest current or in that with the least? Excessive flux densities will hardly cause an abnormal eddy-current loss in the core. The eddy currents depend on the electromotive forces induced in the core, and these are a replica on a fixed scale of that in the primary winding, whether the flux variation, whose double amplitude is constant, takes place symmetrically about the zero line or is all to one side of it. Owing to the greater proportion of the flux which finds a path through the air and copper when the density in the iron is high, it is likely, however, that the eddy currents in the conductors and in any neighbouring metal outside the core will be abnormally great. Some time ago an account appeared in the technical Press of the carrying out of a demagnetizing process on some transformers in order to remove a permanent increase of the hysteresis loss which was attributed to the effects of abnormal residual magnetism. Although this residual magnetism was said to be due to large momentary overloads, there is no doubt that it was really caused by the abnormal fluxes obtained on switching in, to which reference is made in the paper, for an overload would not raise the flux density but rather reduce it owing to the primary voltage drop. The gradual decay of the initial abnormal magnetizing current may be supposed to act as an imperfect demagnetizing process, which should certainly help to remove the permanent effects of the excessive flux, if it does not do so completely. But if the transformer be switched in on overload, the circuit breaker will at once come out again before the flux conditions have become normal. Under these circumstances we may expect the residual magnetism to be both greater and more permanent than usual. The paper is most interesting and instructive, and is certain to be frequently referred to for the sake of the oscillograms it contains. For the greater convenience of such reference it would be a great improvement if the author would add to each figure, before publication in the *Journal*, a title giving all the data for the conditions to which the oscillogram refers.

Professor E. W. Marchant (*in reply*): I am sorry that I did not make reference in the paper to the original investigation mentioned by Professor Fleming, which was described in Volume 21 of the *Journal* over 25 years ago. My bibliography is not by any means complete, because if I had made it complete it would have been very long and would have included a great many papers mentioned in Mr. Duddell's bibliography in connection with his Presidential Address on "Pressure Rises." * I therefore restricted it as far as possible to papers published since 1913. I shall certainly refer in the final form of the paper to the experiments which the President and Professor Fleming have mentioned. The phenomenon of current-rush in the transformer is very old, but I think it is important that it should be emphasized nowadays, because it is becoming so much more important with the lower frequencies and the larger sizes of transformers that are being used. I hope, as Professor Fleming suggests, it will be possible to make a great many tests with oscillographs on large oil switches. We have far too little information at present, and those who have the facilities, I am sure, would be able to obtain very valuable information.

Mr. Everest has referred to the method of making the test. The chief feature of the pressure wave in my figures is a timing function. I was investigating mainly the current-rush. If one were investigating the pressure-rise it would be much better to put the oscillograph between the neutral and the terminals, and so measure the pressure between the neutral and the end of a phase.

Mr. Everest asked what procedure should be adopted to avoid leaving the transformer in an undesirable condition. The simplest plan I can suggest is to switch the load off the transformer secondary before the primary circuit is opened. If there is only magnetizing current through the transformer, the current will be a lagging one. An oil switch nearly always opens circuit at zero current, which in this case will be nearly the maximum point on the pressure curve, i.e. nearly at the point when the flux through the core is zero. This is not an absolute cure, but it reduces the risk of opening circuit when the flux through the core is near its maximum, which is really the dangerous case. If the transformer switch is opened when the transformer is working on a non-inductive load it will almost certainly open at zero point on the current curve, i.e. at zero point on the E.M.F. curve, which, of course, will be the instant when the flux through the core is a maximum. There is less risk when the transformer is working on an inductive load, and the more inductive the load the more certainly will the ordinary oil switch open circuit at an instant when the flux is small. There are many methods that suggest themselves, such as gradually reducing the pressure on the transformer before the circuit is opened, or some form of phase-control relay which only allows the switch to be opened at a definite phase instant, but these all involve additional appliances and control apparatus.

With regard to pressure surges in induction motors, I had no opportunity of examining these experimentally, as the motors I tested were all of the squirrel-cage type, in which the most marked phenomenon was the current-rush. Closing one of the rotor circuits when switching would certainly avoid serious pressure-rise, but of course it gives rise to a current-rush. I can see no great advantage in having one terminal of the stator winding connected first to the line; if the neutral point of the motor is connected to the neutral point of the system there will be a surge, when the one pole is connected, as great as that which would occur when the switch is closed in the ordinary way.

I think Mr. Everest's suggestion of avoiding remanent magnetism in the iron by leaving the transformer connected when the rotary converter slows down is a good one: it will certainly prevent the possibility of the rush reaching such large values as it would do if remanent magnetism were left in the iron. Of

* *Journal I.E.E.*, 1914, vol. 52, p. 1.

course there will be a very considerable rush even if we have no remanent magnetism, but it will not be so serious as the rush with remanent magnetism of the wrong sign.

Professor MacGregor-Morris asks whether I have observed any pressure-rises such as he describes, when the switch is closed. I presume the motor he refers to is one with a wound rotor, as I have already explained, in my reply to Mr. Everest, that the induction motors which I tested all had squirrel-cage rotors, and I do not think there is any possibility with such motors of a serious pressure-rise. I was very interested to hear Professor Morris's description of the method of using the direct-current ammeter for investigating these rushes. That gives a very simple method of seeing how long the rush lasts. It is very difficult indeed to say how long the rush will last with any particular size of transformer. In the tests we made I obtained on a 100-kw. transformer a rush which lasted as long as 2 minutes or more ; and in the 1,500-kw. transformers the rush, for the particular switch-in for which I was able to get a record, did not seem to last very much longer, although one would have expected it to do so. The evidence that one has of the strong hum in the transformer lasting for as long as 30 minutes, shows clearly that the effect does last, under very unfavourable conditions, for a long time.

I was exceedingly interested in the description given by Mr. Brazil of the transients he has observed. He puts the greater number of dangerous transients down to resonance. Resonance gives rise to very high pressure under unfavourable conditions, but, as I have pointed out in the paper, if the circuit which is being connected is resonant to the main frequency we cannot get a higher pressure on the system than that due to the resonant condition, i.e. we do not get, at the instant of switching in, any other transient which will give rise to excessive pressure. The method he described of putting in a choking coil at the instant of closing the switch in order to reduce the pressure is very interesting, but the arrangement mentioned by Mr. Everest of closing one circuit of the rotor of the induction motor should be quite as effective, and of course avoids the necessity for additional apparatus.

Professor Howe referred to the interesting experiments that he made with a small 5-kw. transformer, and to the rush lasting such a long time. I have already dealt with this subject. With regard to his point about $d\,B/d\,H$, it would perhaps have been better to have stated in the paper that the essential feature of the iron to give a flat magnetizing-current curve is that the rate of change of B with change in H must be small. There is *practically* not much difference between that statement and the statement that the iron has large permeability, though there is of course an academic distinction.

Professor Howe also raises a point with regard to the cause of skew symmetry. If the curves of magnetizing current have the same size of positive and negative wave it is difficult to understand how there can be much remanent magnetism. There may, I think, be sufficient to cause a considerable difference in the shape of the hysteresis curve ; at least that seems to me to be the only possible explanation of the curves shown in Fig. 4. With phenomena like these it is almost impossible to get an exact mathematical explanation of all the phenomena observed. The hysteresis loop is not a form that lends itself very well to mathematical analysis, and I do not think that one can dogmatize about the presence or absence of even harmonics being due to it. Professor Howe states that skew symmetry cannot be caused by hysteresis apart from unsymmetrical magnetism. There *may* be considerable difference between the two halves of the hysteresis loop which is not apparent in the magnetization curve. It is rather a debatable point to decide whether it is accurate to say that the effect observed is due to hysteresis.

When speaking on the subject I did not emphasize a rather curious phenomenon which is shown in Fig. 1, namely, the gradual increase in the smaller wave of current during the first 15 or 20 periods. That, as I have explained in the paper, is due to the continued strong magnetizing forces actually increasing the magnetization in the core up to a certain point, after which the magnetization gradually dies away. I think the magnetization would die away owing to what may be called natural causes. If one applies an alternating magnetizing force to iron, it will demagnetize the iron, due to the shaking up of the magnetized molecules of the material, just in the same way as a piece of iron is demagnetized by the application of an alternating magnetization in a solenoid carrying alternating current. The method of getting rid of the rush by inserting resistances at the moment of closing circuit has been dealt with, and I do not think I need say very much about that. Professor Howe's explanation of the cause of the rush through an induction motor is a very clear way of stating what I intended to state in the paper. The phenomenon seems to me exactly similar to that which one gets on a turbo-alternator when it is short-circuited, and the rush will be of the same order of magnitude. With regard to the number of the harmonics, I measured it by simply counting the ripples. It is an experimental number. The frequency came out at 19 times the fundamental ; there may have been also a 17th harmonic.

Mr. Purser-Fletcher refers also to large pressure-rises due to resonance. These are an undoubted danger ; the rise on the coils nearest to the switch is now very well known and has been guarded against by extra insulation.

Mr. Taylor raised a number of points. First, with regard to the method of eliminating harmonics by paralleling alternators, if one has two machines with bad wave-forms paralleled with each other our experience agrees with what Mr. Taylor says—that one will usually get a better resultant wave than from either machine by itself. With regard to the synchronizing curve given in Fig. 15, the pressure curve on switching off is the pressure curve of the 6,000-kw. machine. None of the pressure curves on any of the machines at Lister-drive station are bad wave-forms ; they are extremely good wave-forms. I have taken a number of oscillograms from them at different times and they have given very good curves, and it was a surprise

to me to find that the synchronizing current between these machines was so irregular. With regard to the third harmonic, we do not get any third harmonic on the pressure wave when taking pressure between the phases. I have already explained why it was that I did not take the pressure between the neutral and the particular phase. With regard to the effect of capacity, a large capacity across a transformer or induction motor is certainly advantageous in keeping down pressure, and I have mentioned that point at the end of the section dealing with the current-rush in switching on condensers. One has to decide whether the risk of breaking down the cable is greater or less than the risk of breaking down the transformer or induction motor. If we have a large factor of safety on the cable, it is best to switch off the transformer with the cable connected, and then the cable will tend to keep down the pressure-rise when the combination is switched off. If the cable is not very good but the machine will withstand a high pressure, then it is better to do the other thing, and switch off the transformer independently of the cable. Certainly, from the point of view of the transformer maker, it is a great advantage to have the cable connected. As Mr. Taylor says, the surges shown in Figs. 11 and 13 are protective because they prevent excessive pressure-rise.

I was very interested to hear what Mr. Wordingham has said about the very early experiments of 25 years ago. I hope he will give us some explanation of why his transformer "jumped."

In reply to Professor Robertson, the rush recorded is about 1·2 times the R.M.S. full-load current of the transformer, but, as I have pointed out in the paper, the actual rush was not by any means as bad as it might have been. It is possible to get a rush 4 or 5 times as large, i.e. 5 or 6 times as great as the full-load current of the transformer. The transformers were mesh-connected on the high-tension or primary side, and star-connected on the low-tension side, the star neutral point being earthed through a resistance, so that, as Professor Robertson points out, the record does not show the worst possible condition in each phase. Professor Robertson's statement about the relative times of closing circuit on the three phases of a transformer implies that the switch contacts on the three phases are made simultaneously, which is not always the case. The oscillograph was connected in the line circuit leading to the bank of three transformers, and it is impossible to say whether the oscillograph was connected in the line which carried the least or greatest current, since that would depend on the instant the switch happened to close in each of the three phases. I was very interested to hear of the attempt that had been made in a certain case to reduce excessive hysteresis by demagnetizing the core; it would, of course, as Professor Robertson points out, prove only a temporary remedy.

I have included in the final form of the paper a title to each of the figures, giving the chief data of the experiment to which it refers.

Manchester Local Section, 12 February, 1918.

Mr. L. B. Atkinson: Nobody recognizes more than I do the immense help to be derived from a mathematical statement of a problem; but to men who are always dealing with new problems, and trying to find solutions, the sort of treatment which the author has put forward in this paper is much more illuminating and leads to a much better understanding of the phenomena which are taking place than such analytical treatment would do. It is perfectly true that all these questions of surges of current and rises of pressure have been forced upon us very largely in connection with alternating-current work, partly because the pressures are higher, partly because the results with large currents are very often more striking, and partly because the result is repeated over and over again. Most of those results, however, except where the question of resonance comes in, have really very little to do with alternating current. Consider the starting up of a current. Assume an electromotive force produced by a secondary battery of negligible resistance; what are the various kinds of circuits to which we can couple it up, and what takes place in each case? The simplest case is a circuit with resistance only. We close the switch and get a current I, which at the moment of closing and thereafter is $I=E/R$. There can be no question of a rise of current beyond the normal, neither surge of current nor rise of pressure. Next consider a circuit with nothing but inductance—that is, of no resistance. In the case of electro-dynamic apparatus in which magnetic changes are taking place very fast, it is almost correct to assume that we have no resistance, because resistance would have only a very small effect. In such a circuit, on closing the switch the current starts and if there is no resistance it will rise steadily. The rate of increase of current is simply the electromotive force divided by the inductance—that is $dI/dt=E/L$. There is no question of a surge of current or rise of pressure; it is a steadily increasing current until something else happens. In the ordinary way the resistance begins to have effect, but at the commencement it is a perfectly steady rise of current with no oscillations and no surges. Let us next take the third case, a circuit which has nothing but capacity. The state of affairs at the instant we close the switch is the same as if the capacity did not exist; in other words the battery is short-circuited at the first instant; here we have a surge of current. In these three cases there is no question of oscillation. When, however, we consider a circuit having both inductance and capacity, at the first instant of closing the circuit the current begins to rise at a rate already mentioned, viz. E/L—that is to say, as if the capacity did not exist. But of course as the current rises the terminal pressure on the condenser begins to increase. So the electromotive force causing the current to rise, which is the difference between the battery pressure and the potential at the terminals of the condenser, is always decreasing, with the result that a time will

arrive when the pressure at the condenser terminals is equal to the pressure due to the initial source. It is clear that from that moment there will be no further rise of current, but a steady flow, and then a decrease of current will begin. But the moment the current begins to decrease the electromotive force due to the inductance, arising from the energy stored therein, acts in the same direction as the electromotive force of the battery. The current therefore continues and raises the pressure across the condenser to a higher point than the electromotive force of the battery. The result is that the current stops owing to the pressure on the condenser having risen higher than the battery pressure. Now, there being a higher pressure at the condenser than at the battery end, the current will begin to flow in the reverse direction, and so we have the beginning of the oscillation. Those are the four simple cases. We may add additional qualities to them if we like; but if we get those four simple cases in our minds we have really got the basis of what we see in the phenomena which are described in the paper. These phenomena, although they are important in connection with alternating current, really belong just as much to continuous current. If some day the author could add to these oscillograms those arising from the switching in of continuous-current motors and the paralleling of continuous-current generators, I believe the results would be quite as instructive. Of course most continuous-current systems are at low pressures; consequently in this case the capacity effects are not so important.

Professor M. Walker: Fig. 11, showing that the long, slow swings are caused by the transformer, I think is not a corroboration of what the author said were obvious things with which we are familiar. It is just one of the sort of things that occur in experiments of this kind, which we recognize when it comes but which is unexpected. I do not know whether the author calculated out the inductance of the transformer and knew beforehand that he was going to get the long swing; but of course when he got it he knew what caused it. It is always that way with these experiments. There are one or two criticisms I should like to make. Is the author satisfied with the explanation he gives of Fig. 1? On page 446 he gives, as an explanation why the current curve begins to come down while the voltage is still of the same sign, the fact that the core-loss current is very great. I feel that he is not satisfied; and the further explanation he has given to-night may be evidence of some shakiness upon that question. We are told, for instance, that the current curve begins to rise at a point where the voltage is nearly zero, and that this of course fixes the position so far as the phase of the voltage is concerned. If we connect three transformers in star, and the current has not merely to pass through one leg but also to find its way through the other two legs, its value at any instant is a function of what is going on in all three legs; and as soon as we depart from a sine curve we get a phenomenon that is extremely complicated. To draw any deductions, one would require that kind of clear insight into natural phenomena which Mr. Atkinson has spoken of. It would be interesting to know from the author whether the transformers were actually connected in star, and whether the voltage was measured across the star, and the current measured in one of the legs. If that were so, then none of the explanations given with regard to magnetizing current and core-loss current would hold at all, because we are dealing with the voltage of the two transformers and with the magnetizing current of only one of them. It is probable that the voltage in one of the legs differed from a sine curve. It would almost seem necessary to have some such state of affairs, in order to make it possible to get a curve as shown in the figure. In Fig. 7 everything is perfectly explicable: the explanation given in the paper requires no further remark. So long as we have voltages in one direction, we have a current that rises. When the current begins to fall, the voltage must change in sign. The flux curve must be the integral of the voltage curve. My criticism is this: that in giving figures of this kind one should, so far as possible, show the connections that were made, and always indicate the direction taken as positive along a particular circuit. I witnessed some experiments made in the Deptford power station by the late William Duddell, for the purpose of finding out why certain cables were continually breaking down. The curves obtained on the oscillograph proved that while the voltage wave of the generator itself was fairly smooth, showing ripples of very small amplitude, the wave-form of the voltage when the generator was connected to a certain number of cables (which gave the right capacity to resonate with the frequency of the small ripples) showed enormously increased ripples, and the form factor of the wave-form was raised to 1·9. These experiments emphasized the great importance of getting rid of ripples in the wave-form of generators. The 1,500-kw. turbo-generator at Lister-drive station experimented upon by the author was designed with this end in view. The field-poles were bevelled so as to give as nearly as possible a sine wave to the field-form, so that the electromotive force in each conductor is itself almost a true sine wave. As a result, the wave-form of the charging current of the cable, as seen from Fig. 11, is very nearly sinusoidal, and the ripples upon it are very minute, notwithstanding the great magnification of ripples that occurs under these conditions. There is no doubt that an investigation of the kind made by the author, in which exact information is given as to the happenings in the circuits under operating conditions, enormously extends our ability to improve the design of electrical machinery.

Dr. W. Cramp: The four sections into which the author has divided the paper admit of classification according to the characteristics of the circuits involved. In (*a*) and (*b*) inductance and resistance only are present, the general ratio, however, being different because of the air-gap in case (*b*). In (*c*) and (*d*) inductance, resistance, and capacity are involved, for although in case (*d*) there is no actual condenser present, there is the equivalent of capacity since an over-excited synchronous machine takes a leading current. Apart therefore from questions involving saturation phenomena, cases (*a*) and (*b*) may be taken together, and likewise cases (*c*) and (*d*). To the former the simple

statement will apply that upon closing the circuit the current is the sum of two terms as shown in Fig. A (1 and 2). Here 1 represents the steady conditions of the circuit and 2 represents an exponential term of which the maximum ordinate M is always equal and opposite to the current ordinate of the steady conditions at the instant of closing the circuit. To cases (*c*) and (*d*) the Steinmetz formulæ apply as given in the appendix, provided that under steady conditions the current in the circuit is leading by nearly $\pi/2$. To case (*c*) such a limitation almost always applies, but much greater caution must obviously be used in applying it to case (*d*). The apparently complicated form of the expression for current given in the appendix becomes much more intelligible when it is recognized that it is simply the sum of three waves as shown in Figs. B1 and B2, viz. the current wave as existing in the circuit under steady conditions (Fig. B1), and two current waves of one frequency, displaced with respect to one another by a quarter period and both having the following characteristics: (1) a sinusoidal form, (2) maximum ordinates decreasing along an exponential curve, (3) a frequency which is $1/[2\pi f\sqrt{(L C)}]$ times the normal frequency. The conditions existing at the instant of closing a circuit can thus be graphically set out by adding the ordinates of comparatively simple curves, and several general deductions are immediately apparent, of which five only have a bearing on this paper. These five are as follows:—

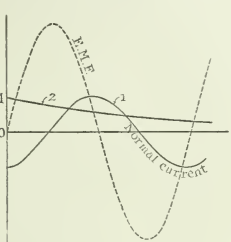


FIG. A.

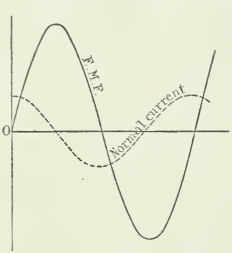


FIG. B1.

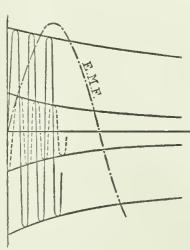


FIG. B2.

1. In cases (*a*) and (*b*), so long as L is approximately constant and large compared with R, the maximum current-rush will occur when the circuit is closed at the instant of zero electromotive force, and its value will never exceed twice the normal maximum current. It is interesting to compare this with the maximum current and pressure-rise, as given in the appendix, for circuits in which C is constant and large compared with L.

2. In cases (*a*) and (*b*), the persistence of the current-rush, hence the question of whether in Fig. 1 the current should cross the zero or not during the second half-period, is determined entirely by the rate of decay of the exponential term, which in turn depends solely upon the ratio R/L. The resistance of the circuit, R, is therefore of very great importance, though it is not mentioned anywhere by the author. If he takes it into account he will find that it will modify several of his explanations. Of course in the case of Fig. 1 variable permeability and remanent magnetism are present as well as resistance, hysteresis, and eddy currents. These factors, however, only modify the numerical values from instant to instant; they do not change the general deductions just given. Thus remanent magnetism may be regarded as a great increase or a great decrease of L according as the initial current is called upon to decrease or increase the existing flux. Similarly an increase or decrease in permeability corresponds exactly to an increase or decrease of L.

3. Increase of frequency in cases (*a*) and (*b*) tends to increase the ratio of the current-rush to the normal current. For the exponential term is relatively increased, and the angle of lag, and therefore also the sine of that angle, are increased. This must not be forgotten when reading the author's statements on page 445 as to the effect of frequency. I should like here to remark that this very important quantity is not mentioned in connection with many of the figures in the paper, and I hope that the author will rectify this omission. (See, for instance, the appendix and also the case dealt with in Fig. 1.)

4. As regards cases (*c*) and (*d*), when the Steinmetz formula applies, the greatest value of the oscillating current occurs if the circuit is closed when E is a maximum. θ_0 is then zero and consequently the first exponential term is zero. This is the case, the author says, in which the maximum pressure-rise is to be expected, and it is therefore of the greatest interest to the engineer. The Steinmetz formula under these conditions becomes—

$$i=-\frac{E}{x_c}\left\{\sin 2\pi ft-\frac{1}{2\pi f\sqrt{(L C)}}\epsilon^{-Rt/2L}\sin\frac{t}{\sqrt{(L C)}}\right\}$$

which is easily calculated for most circuits. The maximum value of the oscillating current would occur when $\tan[t/\sqrt{(L C)}]=2/R\times\sqrt{(L/C)}$. In most cases this corresponds to an incredibly short time after closing the circuit. Assuming that the author's example in the appendix refers to a 50-period circuit, the above

maximum occurs in less than 1/3,000th of a second after switching in, and this accounts for the small effect that the exponential has had in reducing the maximum. For approximate calculations it follows that the maximum current due to the high-frequency oscillation may be taken as $\sqrt{(x_c/x)}$ times the maximum steady current. In the appendix the author finds this ratio to be 19 where this rough rule would give 20.

5. Apart from oscillatory currents the current-rush on switching in a transformer, whether iron in the circuit be saturated or unsaturated, or have remanent magnetism or none, must appear in a definite form in the transformer secondary potential difference, for the flux wave is the integral of the secondary potential difference. Now, so far as one can tell from the paper, the transformer secondaries were always open on the switch-in; consequently, valuable confirmatory evidence of the current curves in Fig. 1, etc., could have been obtained by oscillograph records of the secondary potential difference, and the flux curves corresponding to the abnormal currents could have been very approximately deduced. This point was emphasized by Professor A. Hay in a series of articles in the *Electrician* some 18 years ago, and the curves which he then obtained by a different method are in shape exactly like Professor Marchant's. In Dr. Hay's article reference is made to the fact that the primary electromotive force wave was seldom altered in shape by the current-rushes. This bears out Professor Marchant's experience. But it seems to me that the latter ought to give us far more exact particulars of his circuits before asking us to accept this and other conclusions. For instance, the natural period of the oscillograph is not given, and I was very surprised to see in Fig. 12 that the oscillograph had been connected across the instrument transformers. Can we really expect high-frequency oscillations and harmonics to be transmitted through instrument transformers? I very much doubt it.

The paper suffers generally from a paucity of information which I hope the author will supply. For instance, full details of the constants in the feeder-switching case might be given, sufficient to enable one to check the experimental results by the Steinmetz formula—we also ought to be told whether any load, and if so how much and at what power factor, was on the alternators that were paralleled. Also it is not clear why the author lays such stress upon the difficulty of synchronizing an asynchronous motor-generator. I cannot see why one should try to synchronize it. I think that in future in dealing with the subject of current-rushes it would be well to adopt a definition of the term. I would suggest a definition involving a mere numeric such as "the ratio of the maximum value reached by the current during any period to the normal steady maximum," which was I think the definition adopted by Hay. Professor Marchant in the appendix uses words suggesting a somewhat similar idea, but it is not clear when he speaks of "steady current" whether he refers to the maximum or R.M.S. value. In my formulæ I have adopted Professor Marchant's notation; but I think it a pity to use "C" for capacity. Perhaps the author has some special reason for this. The whole paper bristles with interesting points, some of which, however, are much obscured by the author's inability to get the current and voltage waves in their correct relationships. Certainly also there is something wrong with the diagram marked "after 2 min." in Fig 1, where the last part of the current curve is impossible. Those, however, who have tried to take such tests know the great manipulative skill required, and displayed in this paper, and will forgive small blemishes. They also know what hours of patient work are covered by a few words like those on page 415 concerning the work involved in arranging the phenomena so that they could be studied under known conditions.

Mr. G. A. Juhlin: Although, as pointed out by the author, the phenomena dealt with in this paper are well known, it is important to be able to get a clear picture of what is actually taking place. Referring to

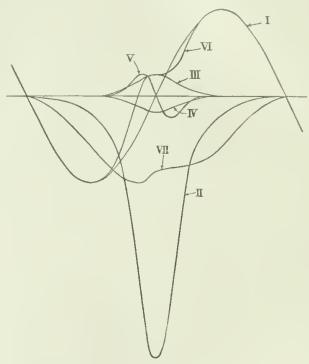


FIG. C.

Curve I. Supply E.M.F.
" II. Magnetizing current.
" III. Resistance drop.
" IV. Flux in air.
" V. E.M.F. due to flux in air.
" VI. Counter E.M.F. in transformer.
" VII. Flux in transformer iron.

the current-rush when switching in a transformer, it should be realized that remanent magnetism is nearly always present on account of the tendency of oil switches to break the circuit at zero voltage. The author refers to the difference, as regards remanence, between lap-jointed transformers and those with butt joints, and it is interesting to note that some Continental manufacturers actually introduce air-gaps in 25-period transformers. Some years ago I saw transformers with $\frac{1}{32}$ inch air-gap at the butt joints. Referring to the question of phase relation between current and electromotive force, as shown in Fig. C, the explanation given by the author does not seem altogether clear. The eddy currents are no doubt of great importance, but it should be pointed out that the resistance losses in the

winding are probably of more importance than the eddy-current losses. Even if all losses are considered, it is difficult to explain the small difference of phase angle, and it would seem that some other influence must be the cause. Fig. 1 shows approximately the conditions in a transformer during the first period. It should be made clear that this is only a rough first approximation, as the problem is indeterminate, and no watt component of the current has been shown. It should be noted that, besides the flux in the iron, there will be a certain amount of flux in the air, which may be considerable when the iron becomes saturated. The counter electromotive force required in the transformer will then be the resultant of the supply electromotive force and the electromotive forces due to the flux in the air and the drop due to resistance. This resultant electromotive force will be somewhat distorted as indicated, and the flux in the iron will therefore also be distorted to some extent. This will in turn necessitate an alteration in the current wave, and this again changes the shape of the electromotive forces due to resistance and the flux in the air. It will be seen that these distortions will have a tendency to change the point at which the current is a maximum, and may to a certain extent explain why it is not a maximum at the point of zero impressed electromotive force. It should, of course, be realized that the whole problem is very complicated, that only a rough approximation can be attempted, and that the above is only put forward as a possible explanation. The current-rush in switching in induction motors is very important. In several cases considerable trouble has been experienced, particularly with squirrel-cage motors, but it also occurs in slip-ring motors. The effect is often more troublesome in induction motors than in transformers, due to the liability of distortions of the winding. In connection with the question of switching in cables, the voltage curves shown are of interest because of the voltage-rises indicated. It is very often difficult to explain failures of insulation, and in this connection it seems possible that an explanation may be found in the sudden rise in voltage occurring when a feeder is switched in, as the voltage would, on account of the very steep wave front caused by a voltage oscillation, pile up on the first few turns of any machines on the system and thus cause trouble. A point of great interest in connection with voltage-rises on a system is that of arcing earths, and some information on this point would be of great value. The question of the usefulness of the equations dealing with the current flowing into a condenser has been discussed by some speakers. It would seem that the practical value is very small, as it is almost impossible to obtain correct values of the constants required to solve them. It would no doubt be possible to obtain correct values for the reactance at normal frequency, but when it is considered that we are dealing with high-frequency oscillations, the results must necessarily be very approximate due to interference of the iron. The bibliography is of great value to engineers who wish to study these questions. As the author has given some references to papers dealing with sudden short-circuits of alternators, I should like to suggest the inclusion in the bibliography of a paper on this subject by Mr. N. S. Diamant read before the American Institute of Electrical Engineers in September 1915.

Mr. C. Vernier: I am more particularly interested in the second part of the paper dealing with transients on underground cables, and I will give a few facts from my experience on a very large interconnected system comprising overhead mains and cables, which may be of interest. The author has referred to the use of cable-charging devices, and mentions that their use has become less necessary on account of the large factors of safety on underground cables. I think he might have gone further and said that they were, in these days, quite unnecessary. I myself have not yet seen such a device; and as for the past 18 years all sorts of cables have invariably been switched straight on without them on the largest cable systems in this country, including such unusual cases as 20 miles of 20,000-volt cable, it is high time that such devices, if they are still used, were relegated to museums. Considering that modern cables have factors of safety varying between 7 and 15 according to their voltage, there is not the slightest ground for apprehending any trouble from this cause. It is not at all unlikely, however, that we may again see such devices brought into use should cables for very much higher voltages (say 60,000 volts and over) be used, where the factors of safety must necessarily be very much reduced. The author has, for obvious reasons, been unable to undertake the investigation of the transients which occur as the result of breakdowns or large short-circuits on a high-tension network. These records would be most interesting were it possible to secure them. On our system I think there is evidence of sympathy between two districts many miles apart, breakdowns in one district almost inevitably leading to breakdowns in the other. This is to some extent explained by the fact that a number of the cables in the first district, which were laid many years ago, are fitted with overload protection, and are subject to fairly frequent breakdowns caused by subsidence from colliery workings. The heavier current-rush before the protective gear operates gives rise to much greater pressure-rises than are experienced with quick-acting protective systems of the balanced type. The latter, without any doubt, greatly reduce the disturbance and damage on a large system fault by cutting out a fault rapidly before the fault current attains a high value. In one or two cases I have noticed what I believe to be evidence of a high-frequency surge, the cable breaking down just at the commencement of a right-angle bend. A surge breakdown on a cable can often be recognized by the fact that the damage consists of a small, clean hole burnt through the paper insulation, the lead being usually undamaged. I am inclined to think that in these cases it is the high frequency of the surge rather than the pressure which breaks down the cable. The pressure-rises one encounters in practice are sometimes remarkable. I have known a surge to jump across two 6,000-volt busbars 6 inches apart in air. The piling up of voltage at points where the line constants change, as, for instance, where an extra high-tension overhead line is connected to an underground cable

I have also met with in practice. In some cases, I have reason to believe, the voltage approached three times the working pressure, and a factor of safety of 5 under all conditions of weather should at least be specified for the insulation at such points.

Mr. F. A. Lawson: The author has taken the case of an induction motor with a squirrel cage. This was run up nearly to synchronism before being switched on. Some time ago I took some oscillograph records of a slip-ring motor, starting it on light load with the starting resistance in. It was in connection with some other work, but out of curiosity I took an oscillograph record of the current flow into the stator in each case. There was a displacement of the exponential type which has been illustrated in some of the diagrams. It was not very big, but it was sufficient to disturb the current and raise it above the axis by about 30 per cent. In connection with that apparatus, at the same time we got out a similar circuit-making device which switched on the current at different points of the electromotive force wave. I found that we got the biggest disturbance of the current flow into the machine on switching in at a period when normally the current would be passing its maximum value. If we take that point of the pressure wave and switch in, theoretically we get the biggest disturbance of current: that, of course, was given by Steinmetz in his treatise on "Transients." I also found that switching in at a moment when normally current passed through zero there was a minimum disturbance—in fact, I could detect no disturbance at all—if we switched in at a period when the current on normal running-up was zero. There was another thing which has an important bearing on a remark made by Professor Walker. On the stator of this induction motor there was a small coil in the air-gap, and on starting up the motor an oscillograph record was taken of the electromotive force developed in the coil by the rotating field. The record shows that the field develops to its full value almost immediately, and certainly within half a period, because we find this wave is practically a sine wave and of constant shape throughout the record. So that apparently the exponentially displaced current-rush is more of the nature of a transient phenomenon and not so much the rush necessary to start the motor from rest. That is the view I am inclined to take.

Mr. H. A. Ratcliff: This paper deals with a most important subject of which our knowledge is rapidly increasing, but of which nevertheless our ignorance is still very great. The mathematical theory of it has been fairly thoroughly worked out, notably by Steinmetz, and is now generally understood; but the great value of experiments such as those described in the paper is that they enable us to visualize the actual nature of the phenomena in question. There is of course some difference between the conditions under which the author conducted his experiments and those which arise in practice on a large high-tension supply system. In the one case the conditions were to some extent controllable and, what is perhaps of more importance, they could be reproduced as often as desired; whereas on a supply system it is invariably the unexpected that happens, and usually, even if it were desirable to do so, the actual conditions cannot be reproduced. Consequently, it is not always possible to make very definite investigations into the nature of transient occurrences. It is also extremely difficult, if not actually impossible, to obtain complete evidence of the conditions of the circuit immediately preceding and during the occurrence, and further the contributory circumstances are frequently not completely known. Transients arising from switching operations on a supply system usually result in momentary excessive values of pressure or current, but of the two phenomena the current-rushes are undoubtedly the more serious in their effects. I consider it is better to switch a high-tension feeder directly on to the busbars than to run it up gradually to full pressure by means of either a motor-generator or some form of feeder-charging gear. In the first case, on a system of any extent and with generators giving a reasonable approximation to a sine wave, it is very unlikely that the momentary abnormal pressure will ever exceed double the peak value of the normal wave, and as most dielectric breakdowns require an expenditure of energy, there will be no excessive strain on the insulation, owing to the absence of any appreciable dielectric loss. If, on the other hand, motor-generators or charging transformers are employed, there may be sustained abnormal pressure due to the accentuation of harmonics in the pressure wave. Current-rushes are far more troublesome in their effects than pressure-rises, not only because of the mechanical damage which they may cause, but also owing to the excessive local high-frequency pressures which may arise as a result of the steep wave-front of the current-rush. Comparatively low values of the current, if of an oscillatory nature, may cause considerable damage in auxiliary apparatus, owing to the relatively enormous values of the locally induced voltages. Evidence of the effects of such transients is furnished by the following: High-frequency sparks have flashed over distances as great as four or five inches. Sparks have passed between neighbouring primary turns of current transformers, indicating the existence of pressures of the order of probably thousands of volts where normally there would be a fraction of a volt. Current transformers have had their primary and secondary windings forced asunder by the enormous mechanical strains set up in them. Fortunately the current-rushes which occur when transformers are switched in may be prevented by the use of switches fitted with auxiliary contacts which first make the circuit through high non-inductive resistances before finally closing it. It is, however, questionable whether this type of switch possesses any advantages for other purposes. On a three-phase system with an earthed neutral, trouble may be experienced when switching in feeders due to the accentuation of the third harmonic, and I should therefore like to know whether the author has made any tests under such conditions. Under favourable conditions the triple-frequency current might attain sufficient proportions to trip balanced protective gear. The pressure wave between phases would of course show no trace of the triple frequency. I quite appreciated the author's reasons for showing the current waves out of their correct phase in many of the figures,

but I cannot help thinking that the visualization of the phenomena concerned would have been easier and more complete had the correct phase relationship been clearly indicated. The switch control illustrated in Fig. 5 was no doubt adjustable to within $\frac{1}{1000}$ of a second by means of the revolving contact-maker, but it is by no means obvious that the switch was equally definite in its operation unless it had a remarkably constant time lag. The reference on page 449 to the starting of induction motors is not very clear, as from the description it appears that the machines are run up from the continuous-current side with the rotors permanently short-circuited. The more usual arrangement is to start such machines from the alternating-current side, with resistances in the rotor circuit, which effectively control the current-rush. The author also mentions the synchronizing of rotary converters and synchronous motor-generators when run up on the alternating-current side, but from his description of the switching operations it appears that the machines in question are of the self-synchronizing type. Further information on this point would therefore be of interest. The method described of switching in an unloaded feeder through a transformer is rather unusual, and would certainly be conducive to resonance effects if the transformer possessed much reactance. The curves in Fig. 10 (*d*) showing a condition of resonance established between the capacity and the inductance of the circuit are very interesting, but it is not quite clear how this condition has been attained. As the current and pressure are in phase their product represents power, and it is presumably the sum of the dielectric loss in the condenser and the copper and iron losses in the adjustable inductance. More information with regard to the connections of the test circuit would be of interest. If the inductance is in series with the condenser, then a condition of resonance gives the effect of a circuit possessing a low non-inductive resistance. If the inductance is in parallel with the condenser, then pure resonance would reduce the main current practically to zero; the small remaining component in phase with the pressure again representing iron, copper, and dielectric losses. I should like to know whether the condenser loss was artificially increased by means of resistance in the circuit and also the nature of the inductance, as my experience is that it is impossible to maintain a stable condition of resonance unless there is a considerable air-gap in the magnetic circuit of the inductance. On a large supply system the most severe transient conditions are usually those which arise when heavy loads or short-circuits are switched off, and I should therefore like to know whether the author has made any tests of this nature, as the resulting information would be of considerable value.

Mr. S. Ferguson: Surges are responsible for a large number of breakdowns of electrical plant, but unfortunately we do not seem to profit by our failures in the past. The causes of breakdowns are very rarely investigated fully, and, if they are, the results are seldom published. Could we not have a better system so as to pool the information on this important subject? It is impossible for every public supply to have its oscillograph and expert operator, but it would be easy to set up a National Testing Authority who could investigate breakdowns and report confidentially to the engineer in charge, and the result could also be made public without disclosing the name of the supply authority. The author, whilst indicating some of the causes of surges, has not suggested means of preventing them. I should like to add to his list of causes, and to make some remarks on preventive measures. One of the chief difficulties with surges is that they may originate in one part of the system and only assume dangerous dimensions when they enter another part with different characteristics, so that the point of failure does not always indicate where the surge arose. For example, a cable surge may be quite harmless in a cable, but when it enters a reactive device, such as a power transformer or alternator, the pressure may be increased enormously. Switching operations as shown by the author are responsible for a large proportion of the surges, and it is now general practice to embody charging resistances in oil switches for transformers, induction motors, etc., of 500-kw. rating and upwards so as to cut down the initial rush of current on closing and to reduce the current before opening. The resistance is only in circuit momentarily during the closing or opening of the switch. It is a pity that the author was not able to show the effects of this preventive device on the switching-in surges. One very fruitful cause of surges is "open arcing." The danger is in breaking the circuit when the current is at its maximum value. Dr. Steininetz has shown that, in the case of a high-tension transmission line of average natural impedance, if the normal current of 200 amperes is broken at its maximum value the rise of pressure may attain three times normal. Oil switches can be relied upon to open the circuit at or near zero current, but air-break apparatus occasionally opens the circuit when the current is a maximum. The heat of the arc is a maximum at maximum current, and the rapid expansion of the air tends to blow out the arc explosively with the current near its maximum value. Happily, air breaks have been eliminated almost entirely from high-pressure systems, but unfortunately they are still retained on low-pressure alternating-current systems. There is no doubt that the surges set up through this cause on the low-pressure side are reproduced on the high-pressure side and ought to be avoided. I am pleased to note that some of the large supply authorities are insisting on oil breakers for the low-pressure side of their systems for moderate-capacity circuits, say 300 amperes and upwards, and I consider this to be a step in the right direction. The dangers of open arcing will impress upon operating engineers the importance of maintaining the correct level of oil in oil switches. One other source of trouble is the arcing earth. It sometimes happens that a high resistance is chosen for earthing the neutral point of the system, with the result that the earth current is not sufficient to trip the overload devices. Leakage relays should invariably be supplied on earthed systems, which can be set to operate instantaneously with very low earth currents of 10 to 20 amperes. Their installation will undoubtedly cut down surges. In the case of earthed systems where

one alternator only is earthed at a time, there is often danger of the attendant disconnecting the earth from the outgoing alternator before he has earthed the incoming machine, with the result that the system is momentarily unearthed. I think the re-distribution of the potential of the system in relation to earth is liable to set up surges which could be avoided by careful operation or interlocks on the neutral switches. The magnitude of the surges produced on breaking a circuit depends on the quantity of energy liberated; it is therefore highly desirable to install reactances on heavy power systems to cut down short-circuit currents. Reactances are exceedingly useful also in preventing high-frequency surges entering alternators. It is true they produce high voltages in the reactance, but air-core porcelain-clad reactances which are now available have an exceedingly high factor of safety. In order to prevent surges in overhead transmission lines from damaging substation apparatus, it is advisable to run a length of underground cable between them. Owing to the lower natural impedance of this cable the surge voltage is reduced considerably on entering it. One piece of apparatus which is particularly susceptible to surges is the instrument current-transformer. I know of several systems with different makes of transformers where trouble has been experienced repeatedly. In one case a flash-over to earth occurred on a current transformer through a 3-inch air-gap whilst the transformer stood a pressure test of $2\frac{1}{2}$ times normal after removal. Can the author offer any explanation why current transformers should so frequently be affected? A possible explanation is that the current transformer is usually connected direct to the outgoing cable, with the result that if cable surges are set up it is the first reactance device encountered, which would cause it to be subjected to high pressures. On the Continent current transformers occasionally have the primary short-circuited with a high non-inductive resistance so as to allow surges to pass without breaking down the transformer. The resistance chosen is sufficiently high to prevent it from materially affecting the accuracy of the transformer ratio. This is a remedy which might well be tried in this country where trouble has been experienced.

Mr. W. T. Tallent-Bateman: I should like to ask the author if he has carried out any investigations in connection with supply systems having electric steel-furnaces connected thereto. There are undoubted evidences that where such a load is connected tendencies to heavy surging have been observed. There does not appear to have been propounded any very satisfactory explanation as to why such surging should exist: I suggest to the author that the subject might prove a very attractive field for exploration if he should ever have an opportunity of following it. A specific case was brought to my notice only a few days ago in connection with a small supply system generating at 3,300 volts. I understand that the system had behaved in a perfectly exemplary manner for some years, until recently after two electric furnaces had been installed. Almost immediately trouble was experienced, and flashes-over occurred on several occasions, where many times the normal voltage must have been present. On two of these occasions short-circuits had resulted by flashing-over at busbars, through an air space of 5 inches. I have had other cases similar to this brought to my notice from time to time, and the whole confirms me in the belief that the trouble must be due in some way to the furnace itself. Such surging might be due to the natural instability of the arc, causing a rapid make and break, which might then be fed back through the transformer to the high-tension side. The arc might die out of itself by being drawn out too far; it might be short-circuited by the falling of metal against the electrodes; or again after being short-circuited the heavy magnetic repulsive action resulting might blow away the fluid metal and thus effect a rupture. It would be very valuable if the author could thoroughly investigate the matter and find a satisfactory solution.

Mr. G. H. Nelson: Being associated with the manufacture of large and small generating units, the various phenomena brought out in this paper are very interesting to me, and the various oscillograph diagrams will be of considerable value for reference purposes when explaining possible causes of breakdowns of generating plant. The paper also brings out the possibilities of the stresses that may be introduced in generators when switching in various designs of machines; and this should be of considerable value to both manufacturers and generating engineers in deciding the types of apparatus that should be installed to give the most reliable systems, for, after all, reliability is one of the most important features to power distribution. The value of the paper would be increased if the author would summarize in tabular form the various points that have been brought out in his experiments, and against each particular point give his recommendation as to what should be done to obviate or prevent damage to generating plant, etc., due to surges. For instance, the author mentioned that "butt" type transformers do not induce the same serious surge when switching on as "shell" type transformers; that the natural frequency of a system should correspond to the working frequency (the resonant case); that reactance coils should be installed to choke down surges, or that protective gear should be operated in conjunction with a contact maker which arranges for the closing of the switch at just the right point in the voltage curve; and that a generator should be insulated to withstand a pressure of so many times its working pressure.

Mr. S. A. Stigant (*communicated*): The author rightly emphasizes the growing importance of transient phenomena to electrical engineers in this country. When switching on to an alternating-current supply iron-cored apparatus such as a transformer which normally operates at an induction of 10,000 or more lines per sq. cm. (40- and 50-period apparatus are here included) the perhaps most apparent immediate result is usually the tripping of the automatic circuit-breaker or the blowing of overload fuses. This is borne out by the figure quoted by the author where, with transformers designed for 10,000 lines per sq. cm., the current-rush may amount to 400 times the normal magnetizing current, considering only magnetic conditions. That

is to say, with a transformer having an impedance of 2·5 per cent and a normal magnetizing current of 10 per cent, the maximum value of the transient current-rush would be equal to the permanent short-circuit current under dead short-circuit conditions at the terminals of the apparatus. The reason for this is to be found in the characteristic shape of the B-H curve and is indicated in Fig. D, where $O\alpha$ is the normal working induction corresponding to Ox the normal

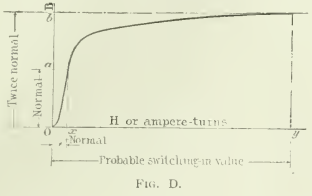


FIG. D.

magnetizing current. When, however, the apparatus is switched in at zero voltage and, say, zero remanence, the flux must rise to the value $Ob=2\ O\alpha$, to which will correspond the magnetizing current Oy, and it will be seen that this is out of all proportion to the normal magnetizing current, depending in actual value on the slope of the B-H curve after passing the "knee" of the curve. As pointed out by the author, however, the actual current-rushes usually obtained are less than outlined above, due to the resistance of the windings, but in any case the resulting currents are sufficiently large to produce abnormal mechanical forces between windings and leads. It would be interesting to know if the author has ever experienced actual distortion of transformer windings or leads from coils to terminals which were directly attributable to excessive magnetizing current-rushes. The ill-effects arising from the heavy mechanical forces generated would doubtless be cumulative, and while initial switching operations may produce no apparent damage, it would seem that many unfavourable repetitions would certainly tend to displace the windings and ultimately produce a breakdown of the transformer. In the case of single-phase transformers it is not impossible to switch on or off at zero current, but in polyphase transformers it is obviously not possible to switch off all phases simultaneously at zero current; and in regard to this I should like to know if the type of transformer connection —i.e. delta-delta, delta-star, star-delta, etc.—has any influence on the magnitude of the current-rush. In the case of transformers normally working at a high induction the initial current-rush at switching in can be very materially reduced by the inclusion of auxiliary switching resistances which are inserted in the circuit at the instant of making contact and afterwards short-circuited. Figs. E and F * illustrate their effect on the transient current-rush of a 20-kw. transformer, the resistance in this case being of such a value that it takes 5 per cent of the supply voltage on no load. There seems to be, however, no real need indiscriminately to equip switches with these resistances, but where trouble is experienced when switching in their use is fully justified. With regard to the switching in of cables, particularly extra-high-tension cables, I am of the opinion that voltage surges are of considerably more importance than current surges. In reading through the paper one might incline to the opinion that the author gives undue prominence to current disturbances at the expense of voltage transients, so that the question naturally arises as to why these investigations were conducted. Were troubles actually experienced on the Liverpool Corporation's system and if so of what character and how were they made apparent? Fig. 11 (*c*) and 13 (*b*), showing the low-frequency oscillation at which the cable discharges after switching off, are very interesting, and similar records have been obtained by Steinmetz † and Faccioli.‡ In connection with the current-rush into cables at the moment of switching in, I should like to have the author's opinion as to whether, in the case of a multicore cable at its normal working temperature, say in the neighbourhood of 65° C., there is any likelihood of decentralization of cores due to the mechanical forces generated by the excess currents flowing.

FIG. E.

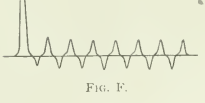


FIG. F.

Professor E. W. Marchant (*in reply*): A statement such as Mr. Atkinson's is of great value: it gets right back to the fundamental principles, and I am sure it was most interesting to all of us. There is little opportunity for making experiments on direct-current circuits, though I have no doubt we should get some valuable results if we were to do so. I do not think that, practically, the case is so important as that of the alternating-current circuit. The case of a resonant circuit from the point of view of switch-

* Taken from "Switching Phenomena in connection with Electrical Machines and Transformers," by Dr. W. Linke, *Elektrotechnische Zeitschrift*, 1914, vol. 35, p. 757 (abstracted in the *Electrician*, 1914, vol. 74, p. 382).

† C. P. STEINMETZ: "Electric Discharges, Waves and Impulses."

‡ G. FACCIOLI: "Electric Line Oscillations," *Transactions of the American Institute of Electrical Engineers*, 1911, vol. 30, p. 1803.

ing-in phenomena is really the safest, as no high-frequency ripples are produced.

Professor Walker referred to the low-frequency oscillations which occur when a cable is switched off. I did not anticipate this result when I started the experiments. I was very interested to see it; and the explanation of it is of course fairly obvious. I think if Professor Walker will read the paper in its final form the explanations given will appear consistent with the facts.

The transformers were mesh-connected on the high-tension side and star-connected on the low-tension side. The rush recorded, therefore, is really a combination of the rushes to two transformers, in one of which it may be assumed that the rush is small, while in the other it is large. That will be the actual condition, if the switch closes the three circuits of the three phases simultaneously. It would perhaps have been more exact to take account of this and state that the current was displaced either 60° or 120° from its correct phase, depending on which of the two branches of the mesh was the one in which the rush happened to occur; but a phase difference of 1/12th of a period is hardly noticeable on the curves. The fact on which I wished to lay the greatest stress was the magnitude of the current-rush, because it is that which determines whether the rush is likely to injure the transformer. It is interesting to hear Professor Walker's description of the experiments he witnessed at Deptford. Resonance is a great source of danger, not when switching in, but under ordinary steady conditions; and, as Professor Walker says, it is most necessary to get rid of ripples. The potential wave-forms of the machines at Lister-drive are certainly very good. We found a 25th harmonic which, of course, appeared to be relatively large on the charging-current curve.

Dr. Cramp has classified the results recorded in the paper. With his two cases (*a*) and (*b*) in which he states only inductance and resistance are present, I should like to emphasize the fact that the inductance in the circuit of a transformer when it is switched in is not constant. The cause of the current-rush being so large is that the remanent magnetism makes it difficult for the transformer to build up a large enough flux change to provide the necessary counter electromotive force. The assumption that L is approximately constant would result in a current-rush only 2 or 3 times the normal magnetizing current, instead of 200 or 300 times as great, as it is in practice. The persistence of the current in a current-rush, also, is not determined by the resistance in the circuit; if it were, the rate of decay could be easily calculated. It depends on the remanence and coercive force of the iron of which the transformer is made. The more difficult the remanent magnetism is to destroy, the longer the current-rush will last. Increase in frequency produces no perceptible increase in the ratio of the current-rush to the normal current. The effect of frequency to which I have referred is only indirect; the lower the frequency the more completely is it possible to saturate the iron of the transformer without over-heating it, and therefore the more serious the current-rush to the transformer is likely to be. I do not agree with Dr. Cramp that the current-rush to the transformer primary must necessarily appear in the wave of secondary potential difference. The current-rush is purely a magnetizing rush and only occurs in the primary circuit; except, therefore, in so far as the magnitude of it alters the value of the back E.M.F. necessary for the primary, it will not produce any effect on the secondary circuit. The E.M.F. waves obtained on the transformer secondaries would, I believe, be almost pure sine curves, like the wave of potential difference on the transformer primary. The natural period of the oscillograph was about 1/3,000th of a second. Dr. Cramp expresses the opinion that it is not to be expected that high-frequency oscillations would be transmitted through instrument transformers. Iron will respond to alternations at a frequency of more than a million a second; and if this be so, there seems no reason why high-frequency oscillations should not be transmitted through instrument transformers. I have given some further conditions of the tests in the paper (in its final form) which will, I hope, be of value.

The only reason for synchronizing an asynchronous motor-generator is to prevent too heavy a current surge when the circuit to it is closed. With a machine having a squirrel-cage rotor the current-rush is, as these tests show, very large, and unless the machine were brought very nearly to its right speed serious damage might be done. The definition of a current-rush by Dr. Cramp is very useful. I think the ratio should be that of the crest value of the rush to the crest value of the normal steady current. I think if Dr. Cramp looks at Fig. 1 ("after 2 min.") he will find the curves are correct, though I admit that it is rather confusing not to have them in their proper phase relationship.

With reference to Mr. Juhlin's remarks, we have found that an oil-break switch usually opens circuit near zero current: air-break switches, of course, open the circuit anywhere in the phase. I was greatly interested in his description of the transformers that he had seen with air-gaps in them in order to eliminate current-rush. The diagram he gives of the phase relations between flux, electromotive force, current, and resistance and leakage drops, is most valuable and shows the phase relationship of these quantities very clearly. I appreciate the fact that resistance is usually more important than equivalent resistance due to eddy currents; though I remember a rough rule given by Eborall years ago for the resistance of an alternator, in which he stated that the total resistance of the armature could be taken to be twice the resistance measured by a direct-current voltmeter and ammeter. The phase relationship given in Mr. Juhlin's Fig. C does not differ very much from that shown in Fig. 1 when allowance is made for the fact that the curves in Fig. 1 are not shown in their proper phase relationship. His reference to the possibility of distortion of the winding of induction motors due to current-rush emphasizes the necessity for eliminating it as far as possible.

Mr. Vernier refers to cable-charging devices. I have only seen one in this country. As he says, cables

have such a large factor of safety, nowadays, that such devices have become unnecessary.

It would be of very great interest to obtain oscillograph records of breakdowns and large short-circuits, but these experiments would prove very expensive. We should certainly consider, however, whether it would not be worth while to attempt something of the kind. It is impossible to make such tests on a laboratory scale and then use the data so obtained to predict what will happen on a large scale, since the large-scale conditions of the arc are totally different. The study of transient phenomena is only beginning, and they will, I feel sure, require much detailed investigation in the future.

The results of Mr. Lawson's experiments agree with those found in our tests, i.e. that the greatest rush occurs when the circuit is closed at the instant which corresponds to maximum current. The experiment he describes with a search coil is most interesting, as it proves conclusively the almost instantaneous production of the magnetic field in the induction motor; the rush that occurs, therefore, must be similar to that which takes place when a short-circuited transformer is switched in, the dying down of the transient being controlled by the resistance of the circuits of the rotor or secondary.

Mr. Ratcliff stated that, in his opinion, current-rushes are more likely to do injury to a system than pressure-rises. I am interested to hear that he regards these phenomena as likely to cause trouble; that is certainly my own view, and it is the chief reason for the writing of this paper. His description of the destruction of current transformers illustrates most clearly the enormous forces that may be brought into play by current-rushes. A switch that temporarily puts in a high resistance when switching in a transformer should help to keep down the rush very effectively. I have never observed any serious transient on a feeder due to the presence of a triple-frequency current. Such currents flow in the neutral wire connecting generators coupled in parallel, with their neutrals connected, or round mesh- or delta-connected circuits. The motor-generators I tested were started in the way Mr. Ratcliff suggests. It was the only way of starting them, as the rotors of the induction motors were squirrel-cage and there were no pony motors fitted. The rotary converter for which a curve is given in Fig. 17 was of the self-synchronizing type, and the paralleling simply consisted in short-circuiting the auxiliary induction motor. In the feeder tests, the feeder was not switched in through the transformer but on to the high-tension side of the transformer by an oil switch. In the curves shown in Fig. 10 (*d*) the inductance and capacity were in series, thus giving the effect of a low non-inductive resistance for the whole circuit. The condenser was not shunted by a non-inductive resistance to increase its apparent dielectric loss. The inductance used was one with an adjustable iron core, which varied the air-gap in the iron circuit. No difficulty in maintaining resonance was experienced. I was, unfortunately, unable to make any tests on the transients which occur when heavy loads or short-circuits are switched off, but I hope many such tests may be made; they are undoubtedly, as Mr. Ratcliff says, the chief source of the trouble. Mr. Ferguson's suggestion of a National Testing Authority to investigate breakdowns is a most valuable one. When the President's proposal of a National Proving House takes shape, this will, I hope, be one of the branches of work which ultimately that institution will undertake.

Mr. Ferguson's question as to the cause of breakdown in current transformers is difficult to answer in a general way; there is little doubt that the majority of breakdowns are due to surges to which the current transformer offers a very high impedance, thus giving rise to a high pressure between the terminals. A current-limiting reactance in series with the feeder would provide an effective safeguard against such trouble. I have not made any tests on circuits supplying electric furnaces; the heavy currents taken by such furnaces must often give rise to dangerous transients during switching operations, as Mr. Tallent-Bateman suggests.

It is difficult to summarize the points brought out in the paper, as proposed by Mr. Nelson, and still more to state generally the best method of protection against surges. I did not intend to suggest that circuits should be arranged to give resonance for the working frequency, but to point out that, when that condition did occur, there could be no high-frequency transients when switching in. The arrangement of a contact maker which would ensure that the circuit would be switched in at a particular point in the phase is, I am afraid, not very practicable; the best safeguard is to design the plant so that it can withstand any surges that are likely to arise.

Mr. Stigant refers to the possible distortion of the windings of a transformer by current-rushes. This is quite possible, but the rush is not large enough to produce it in these tests. The method of connecting the transformer would not affect the current-rush through any single transformer, provided that the transformer were one of three independent transformers connected to the three phases. If a combined three-phase transformer were used, the method of connection might easily produce some result, since the state of magnetization of one of the cores would affect the magnetism of the others. With regard to the possibility of decentralization of the cores of a multicore cable due to current-rushes, I do not think this is likely with the paper-insulated cables used on high-tension circuits.

THE MECHANICAL DESIGN AND SPECIFICATION OF THE TURBO-ALTERNATOR ROTOR.

By S. F. Barclay, Ph.D., B.Sc., Associate Member.

(*Paper first received* 7 *November*, 1917, *and in final form* 26 *January*, 1918; *read before* The Institution 21 *March*, *before the* Yorkshire Local Section 12 *March*, *and before the* Manchester Local Section 26 *March*, 1918.)

The objects of this paper are to review the conditions underlying the mechanical design of the high-speed alternator rotor, and to suggest a specification for the guidance of the purchaser's technical adviser.

The history of the development of the alternator for direct coupling to high-speed steam turbines is very similar to that of most machinery. The old construction has been applied to meet the new conditions, and, as failures have developed, improvements have been introduced to overcome them. The process is lengthy and wasteful, but essentially natural.

The outstanding feature of the earlier electrical machinery was the disregard of mechanical soundness. Reliance was placed on string and tape in an astonishing degree. Nothing has led to the development of electrical machinery from the mechanical point of view more than making alternators suitable for direct coupling to high-speed steam turbines. With the advent of peripheral speeds of over $4\frac{1}{2}$ miles per minute the unsound construction of earlier times has disappeared, and the modern turbo-alternator rotor is not surpassed as a high-class engineering production. The need for the use of material of the highest grade is obvious when it is recalled that at the periphery of a 31-in. diameter rotor running at 3,600 r.p.m. a mass of 1 lb. exerts a centrifugal force of $2\frac{1}{2}$ tons, and in the case of a 5,000-kw. alternator at 3,000 r.p.m. the total centrifugal force at the normal running speed is about 15,000 tons. The kinetic energy of such a rotor at the normal running speed is about 7,000 foot-tons—equal to the muzzle energy of 23 75-mm. field guns and sufficient to hurl 380 lb. of steel a distance of 6 miles. It is clear that to eliminate weakness of construction by the lessons of failure is not a permissible policy with such machinery. The precise nature of the duty at the various parts of the rotor must be thoroughly investigated, the material employed must be of the highest grade, and the factor of safety must have a satisfactory value.

The conditions to be faced are most severe, and the author doubts if they are sufficiently well realized by either user or maker. Even with the smaller sizes of high-speed machines that marked the progress of a few years ago, mechanical failures were not unknown, and the author is of the opinion that with the machines for large outputs at from 1,500 to 3,600 r.p.m., such as are being made to-day, mechanical failures must result unless greater attention is paid to the excellence of design and of material.

It is somewhat remarkable that the specifications drawn up by consulting engineers make little attempt to ensure mechanical excellence, although the electrical performance is usually very fully stipulated. Occasionally one notices in specifications that the engineer has some uneasiness with regard to the mechanical performance and endeavours to safeguard his client's interests by specifying the tensile qualities of the rotor steel and by calling for an unusually high overspeed test, but one never sees stipulated the all-essential permissible ratio between the stress and the quality of the material *in the direction of the stress*. For instance, it is not sufficient to test the tensile qualities of the steel in an axial direction at the end of the shaft when the maximum stress is in the body of the rotor in a radial direction; nor is it logical to display concern in the quality of the material and disregard the complementary factor—intensity of stress. It will be shown later that an excessive overspeed test is on the one hand undesirable, and on the other does not necessarily establish mechanical soundness.

Comparison of the Solid and the Laminated Rotor.

Even up to a few years ago the controversy as to the relative merits of the salient-pole rotor and of the cylindrical rotor still flourished, but with the advent of large outputs at high speeds the former type has now disappeared. There still remains, however, some discussion as to the advantages of the solid as compared with the laminated rotor. From the electrical point of view, for polyphase work there is no essential difference. For a given design theoretical considerations would indicate that the maximum momentary short-circuit current would be less with the laminated than with the solid rotor, for the reason that there is a greater resistance to the flow of the rotor eddy-currents at the moment of short-circuit, on the creation of which depends the momentary loss of the stator self-induction. Since, however, the alternator with a solid rotor can quite well be designed to stand short-circuit at the terminals without damage, this property of the laminated rotor is without practical value. On the other hand, the better electrical contact that is established between the slot wedges with the solid rotor causes the rotor to constitute a more effective damping winding and so gives greater electrical stability. With an unbalanced load there is less heating with a laminated than with a solid core, but again this quality is usually of no advantage, since by exercising certain obvious precautions the solid rotor can be employed successfully with any degree of unbalanced load that occurs in practice. In a normal turbo-alternator the output is limited by the rotor heating,

and it is obviously a great advantage of the solid rotor that the ventilating channels can be arranged to secure the best cooling effect, whereas with the laminated rotor they have to be provided where mechanical considerations permit. The essential weakness of the laminated rotor is the presence of the central hole through which the shaft passes. On account of the thickness of the metal between the bottom of the slot and the inner bore being comparable in magnitude with the diameter of the bore, the maximum stress exceeds considerably the average stress, and the design becomes limited by the stress at the inner periphery. As an example, with a 3,500-kw. alternator at 3,000 r.p.m. the maximum stress on the inner fibres exceeds the average stress across the belt of metal by about 20 per cent. In addition to the stress caused by the centrifugal force, there is to be considered the stress due to the shrinkage fit of the stampings on the shaft. To ensure that the core shall remain tight on the shaft when running at the overspeed, the amount of the shrinkage must exceed the amount by which the core opens due to the centrifugal force. Thus, in the case being considered, the shaft diameter would be about 12 inches, and at the overspeed of 3,600 r.p.m. the inner bore would increase about 0·018 inch in diameter. Making allowance for normal tolerances in workmanship, the shrinkage would need to be not less than 0·02 inch to ensure that the core shall always remain tight on the shaft. This requirement for mechanical soundness gives an appreciable increase to the stress in the core discs. Just at this part of the core disc where the stress is a maximum the strength is very considerably reduced by the keyway cut into the lamination. The weakness could be avoided if instead of cutting the keyway in the disc a projecting tongue could be formed to register in a keyway in the rotor shaft. Such an arrangement is not practicable, because the tongue would prevent the inner bore of the core being machined. To give the essential good fit of the core on the shaft, the core should be bolted solidly together between stout end plates and be bored to a smooth surface, and the shaft then be ground to suit with the necessary shrinkage allowance. Apart from being desirable to ensure a good fit, it is vitally important to bore out the core in order to remove the metal that is strained and weakened by the punch. This matter will be referred to later.

The solid rotor has the great advantage that the bursting stress is always less than the stress in the tooth, and the former stress has therefore never to be considered. A comparison of the hoop stress for a laminated and a solid rotor is shown in Fig. 1 for a 3,750-kw. alternator. It will be seen that even with a much deeper tooth the maximum stress in the forged rotor is only 13,800 lb., against 34,500 lb. in the laminations.

Another matter to receive consideration when discussing the laminated rotor is the question of the material available for the core discs. Such material is prepared by rolling down hot slabs into sheets of the thickness required. The structure of the steel is influenced very considerably by the finishing temperature of rolling and by the rate of cooling.* With a large, thin sheet it is impracticable to maintain a uniform temperature throughout, and a micro-examination after rolling shows appreciable variations in the crystalline structure at different parts of the sheet. Careful annealing, by the re-crystallization that results, does much to remove such variations, but no matter what care the manufacturer may exercise, some variations in the finished sheet are unavoidable, and particularly so when thorough annealing is not permissible on account of the lowering of the tensile strength. Moreover, the fibre is determined by the direction of rolling; the effect of the final passes predominates, although the earlier passes have a slight permanent effect. Even at a given part of a given sheet the ductility is found to vary somewhat according to the direction chosen, although the tensile strength may be fairly uniform. Minute local imperfections that would be without effect on a fairly thick plate may appreciably weaken a thin plate. Since material of this kind is inherently less dependable than a high-class forging, the factor of safety should be higher than with the solid rotor, but due to the weakening effect of the central hole the designer has to be content with a lower factor of safety.

To meet the demands of the electrical engineer for steel sheets having a high tensile strength, some manufacturers have taken advantage of the additional strength given by cold working. An interesting theory of the hardening of metals by cold working has been put forward by Sir George Beilby.* By making the final passes through the rolls at a low temperature the tensile strength is considerably increased. The action is to deform the crystals and to produce amorphous material on the surfaces of the gliding planes, resulting in appreciable hardening. Up to a certain point the more the steel is reduced in area the more the strength is increased in this way, but beyond that point the steel is rapidly weakened. The effect of annealing such material is to remove largely the effects of the cold working, by the re-crystallization of the amorphous material that results. The elongation may be brought to a low value according to the extent of cold working—even to less than 1 per cent. Under a tensile test such material breaks abruptly without any appreciable stretching. With the steel sheets that are prepared in this way for rotors, the cold working is not carried so far, and there is usually an elongation of about 5 per cent with a yield point of about 35 tons per square inch and a breaking strength of about 40 tons per square inch. The effect of the cold working with large thin sheets is essentially somewhat uncertain, and such material cannot be regarded as being of a high grade. There is always the chance of the process being carried too far locally and of minute internal flaws being caused. Another danger of material worked in this way and only partly annealed is the possibility of there being what is known as "rectangular brittleness." This remarkable phenomenon is more usually encountered with pure iron and very mild steel, but the author has had experience of it

* *Philosophical Magazine*, 1904, vol. 8, p. 258; *Proceedings of the Royal Society*, vol. 79 A, p. 463; *Journal of the Institute of Metals*, 1911, vol. 6, p. 5.

occurring in some degree with steel of the kind in question. It has been discovered that if steel is worked at a temperature below 500° C., and is then annealed at a temperature below the critical point, it is liable to become coarsely crystalline. It was shown by an interesting experiment by Professor Sauveur, and independently by Mr. H. S. Kipling, that in addition to the critical temperature there is also a critical range of deformation, and if the steel is worked either more or less the phenomenon does not occur. Dr. Stead* found that the property he designated "rectangular brittleness" is due to the material crystallizing with the cleavages at an angle of 45° to the direction of rolling and at 90° to the surface of the sheet. It is obvious that if the crystals are all similarly oriented

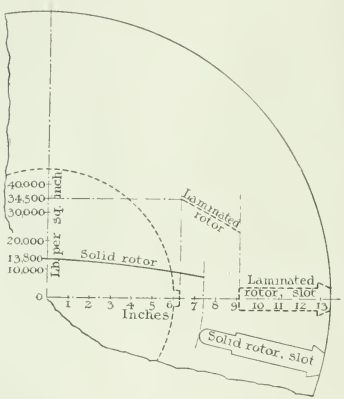


FIG. 1.—3,750-kw. 3,000-r.p.m. alternator with 27-in. diam. rotor. Curves showing the much lower hoop stress in a solid as compared with a laminated rotor of the same diameter. Stresses calculated at 20 per cent above normal speed.

the sheet would be readily fractured if the stress were applied at right angles to any of the three cleavages, although it remains tough in directions at 45° to the cleavage planes. Annealing at a temperature above the critical point would remove this weakness, but it would at the same time largely remove the effect of the cold working and very considerably lower the tensile strength.

Reference has already been made to the weakening effect of punching metal sheets. If a micro-section of the sheet is made it is clearly seen that the effect of punching the metal or, in a slightly less degree, of cutting it with shears is to distort and harden the crystals. Metal that was quite ductile before punching is found to be brittle round the punched edge. It is most important, therefore, that the core should be assembled in a jig and be bored out, since otherwise there would be brittleness and weakness at the part subjected to the greatest intensity of stress.

In place of cold working another method of producing plates of high tensile strength is to employ a high carbon content. The ductility of such steel, however, is not good, and it cannot be regarded as being suitable for the duty. An entirely satisfactory high-tensile plate could be produced using nickel-chrome steel, but a rotor constructed with such plates would be more expensive than a solid forged carbon steel rotor, and would be less satisfactory mechanically and electrically.

Another point to receive consideration with the laminated rotor is the question of the critical speed. Practically always, the running speed is above the first critical speed, and with large outputs at 3,000 r.p.m. the running speed may be above the second critical speed. If the laminations were fairly loose in the axial direction the critical speed of the shaft could be accurately determined, but for mechanical soundness it is desirable to assemble the laminations under heavy end pressure. Additional stiffness may be given to the shaft, the deflection being reduced and the critical speed raised. The stiffening effect is usually not permanent: under the combined action of vibration, stress and pressure, the minute undulations in the laminations are removed, and in the course of time the end pressure which might have been initially 200 tons is found to have disappeared. In the case of a typical 3,750-kw. alternator at 3,000 r.p.m., with a shaft diameter of 12 inches, a core diameter of 27 inches, a core length of 50 inches, and a distance between bearing centres of 134 inches, the first critical speed with the laminations absolutely solid would be about 2,000 r.p.m. and with the laminations free would be only about 1,400 r.p.m. It will be seen that with a newly constructed rotor the critical speed may have a satisfactory value, but after some running there may be a lowering of the critical speed and some vibration may result. The author has had experience of several cases of slight incurable vibration with laminated rotors that has developed after prolonged running, but in only one case was the vibration so bad that the rotor had to be reconstructed.

When high-grade forgings are available the solid forging is undoubtedly preferable for all sizes of rotors for polyphase work. For small outputs the laminated rotor can be made satisfactory, but to employ the construction for large outputs is to take unnecessary risks. It is the author's opinion that for outputs in excess of 3,000 kw. at 3,000 r.p.m. the laminated construction should be employed only when it is impossible to obtain suitable forgings.

For large-diameter rotors at medium speeds thick plates are sometimes employed instead of laminations. This construction is preferable to using thin sheets, but the weakness of the centre hole and the high hoop stress, together with the unsuitability of using rolled plate with a pronounced fibre subjected to high stress in all directions, are still present, and when the critical

* *Journal of the Iron and Steel Institute*, vol. 53, p. 180.

speed is below the running speed, trouble with it is equally if not more pronounced.

Another alternative is the construction of using plates of considerable thickness held together with through bolts with a short shaft length at either end and no central hole. The great weakness of this construction is the difficulty of making the bolts satisfactory. The deflection is due almost entirely to the elongation of the bolts, the area of the plates being large compared with the area of the bolts and the compression of the plates therefore negligible. A very slight elongation of the bolts takes all compression off the plates, and consequently at the underside of the rotor the plates are out of contact. Each time the rotor turns round, stress in addition to the initial stress is thrown on the bolts. In the case of a 1,500-r.p.m. rotor this intermittent superimposed stress is applied and removed over two million times a day. It is claimed for the construction that the variation of stress can be maintained at so low a value that in spite of the rapid variation the duty is within the capacity of the steel. It is to be remembered, however, that the calculated stress may be considerably exceeded. In the first instance, it is difficult to know exactly the initial stress, which is usually determined either by measuring the pull on the spanner tightening the nuts or by measuring the elongation of the bolts. Again, the action of tightening the nuts may impose a very considerable torsional stress. Also, the driving torque imposes a longitudinal as well as a shear stress on the bolts. Above all, a bolt cannot be regarded as being dependable for carrying a rapidly fluctuating stress. The design usually calls for the bolts to be a reamered fit in the plates, and there is thus a sudden reduction of area at the parts where the thread is cut. The added elongation when the additional load is thrown on the bolts by the action of the rotor turning round is not uniformly distributed over the whole length, but is concentrated to an extent dependent on the reduction of area at the short length between the end of the fitting part and the face of the nut. In the course of time this concentration of elongation in company with the weakening effect of cutting the threads tends to cause failure by fatigue close to the nut. With one case that came to the author's notice of a 6,000-kw. 1,500-r.p.m. alternator constructed in this way, it was found that after $2\frac{1}{2}$ years' running some of the plates at the centre of the core had moved slightly out of centre. On dismantling the rotor it was found that the opening and closing of the plates at each revolution, as described above, had caused fretting of the spigots and between the bolts and the reamered holes, and where initially there had been a good fit there was found to be a clearance on the spigot and in the bolt holes of 1/50 inch.

Another disadvantage of the plate construction is apparent when the critical speed is considered. Since the bolt area in tension is small compared with the rotor weight, the deflection in the body of the core is considerable and hence the critical speed is very low. It is almost impossible to avoid some degree of synchronism of the normal speed with the harmonics of the natural period of transverse vibration. The effect of the plates meeting, by the great area of compression they offer, prevents any appreciable swing of the rotor beyond the neutral axis. Vibration is thus damped, and such a rotor has no real critical speed, but there may be sufficient vibration to be appreciable.

Such a construction can be seriously considered only with relatively large and relatively low-speed rotors, and is only to be employed when forgings are unobtainable.

The Maximum Desirable Diameter of the Solid Forged Rotor.

The forged rotor having no central hole is very much stronger in its resistance to bursting than is the laminated rotor, as shown in Fig. 1. It can be shown mathematically * that a minutely small hole through the centre of a rotating cylinder doubles the stress. In addition to the gain due to the omission of the hole, there is the greater area of steel to carry the load. The capacity of the added area to carry load is considerably greater than the extra load due to the centrifugal force of the added metal, and so altogether the bursting stress is so low that it has not to be considered.

The maximum stress with the solid forged rotor is always in the tooth, but the stress never reaches a high value, the maximum rotor diameter being determined by other considerations.

With the type of winding now in universal use, of concentric coils of flat copper strip, there is a fairly clearly defined limit to the rotor diameter that may be employed for a given speed. There are to be considered the stability of the end windings exterior to the core, the pressure on the insulation between turns, and the retention of the end windings against the action of centrifugal force. In the case of a 5,000-kw. alternator at 3,000 r.p.m. with a 31-in. diameter rotor, when running at the overspeed of 20 per cent above normal the average value of the maximum pressure on the insulation is about 5,000 lb. per square inch. The desiderata of the insulation between turns are good electrical properties, capacity to stand high temperatures without deterioration, and mechanical strength. The author is very strongly of the opinion that pure, hard mica is the only material that is really suitable for the purpose. Asbestos sheet is sometimes employed, but it cannot be regarded as being a suitable material. The electrical properties of the asbestos may perhaps be made sufficiently good by careful impregnation, and it is, of course, very suitable for resisting heat, but mechanically it is not good. The space available for the rotor copper determines the rotor output and hence the alternator output, and it is obvious that the thickness of the insulation between turns must be reduced to a safe minimum. A thickness of 0·01 inch cannot be exceeded without unduly adding to the size of the machine for a given output. However carefully asbestos may be made, with such a thickness it is not possible to avoid weak spots. The copper is never absolutely flat, and any high point is very liable to crush the asbestos locally and cause short-circuiting between turns. Pure, hard mica is very good mechanically and does not yield locally in this way.

* Morley's "Strength of Materials," art. 126.

Fig. 2 shows a cross-section through one of the rotor coils of such an alternator, and there is drawn to scale on top of it a block of steel equal in weight to the centrifugal force exerted by the coil. When it is considered that the length of each outer coil exterior to the core is about 4 feet, it will be appreciated that the difficulty of preventing any side-slipping of the coils, however well they may be supported, may become a limiting factor of speed. The illustration does not exactly reproduce the running conditions, since the centrifugal force is not uniform throughout the coil as is the pressure due to the weight, but varies from zero at the bottom to a maximum at the top. The sketch nevertheless serves to convey a much better idea of the duty than a mere statement of figures can do. As a structure such a coil is not well adapted to carry a great load without distortion—particularly having regard to the high-frequency vibration that must be present in some

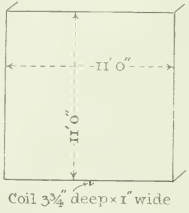


Fig. 2.—5,000-kw. 3,000-r.p.m. alternator with 31-in. diam. rotor. At the overspeed of 20 per cent above normal the maximum pressure on the insulation between the rotor turns is 5,000 lb. per sq. in. In the case of a coil 1 in. wide it is equal to supporting a block of steel 11 ft. square of the same length as the coil.

degree, however perfect the balance. Moreover, the tendency to move due to expansion which may not take place uniformly with all the turns at either end of the core, and to the low coefficient of friction between the polished surfaces of the copper and the mica, adds to the difficulties.

The stability of the coils is much improved as the breadth of the strip is increased. The practice of most makers seems to be to employ rather a large number of coils with a relatively narrow section of copper—six or seven coils per pole being common. A far better arrangement is to use fewer coils of greater copper breadth. Also, reducing the ratio of wound slots to slot pitches is not only better mechanically, but is more effective electrically, as shown by Dr. S. P. Smith.* The limitation in this direction apart from electrical considerations is the section of strip that can be handled conveniently.

Under steady compression between flat surfaces mica can stand great loading before failing. In service, however, it is to be remembered that the conditions are not nearly so ideal. There is always some degree of high-frequency vibration present and the surface of the copper is never quite flat. For these reasons a big margin of safety is necessary.

Whereas the limitations due to end-coil stability and insulation pressure are indefinite, as will be seen later the limitation due to the difficulty of retaining the rotor end-windings is quite definite. Having regard to these circumstances, the author believes that for a normal speed of 3,000 r.p.m. a 32-in diameter rotor will come to be regarded, if not as the maximum permissible size, at least as the maximum desirable size. The peripheral speed of such a rotor is 25,120 feet per minute. For a given peripheral speed the centrifugal force of a given mass is inversely proportional to the

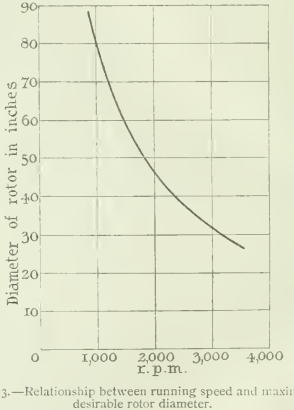


Fig. 3.—Relationship between running speed and maximum desirable rotor diameter.

radius. With the larger diameters, however, it will be found that with an increase of diameter there is roughly a corresponding increase in the weight of the various parts, and for speeds below 3,000 r.p.m. the desirable peripheral speed is actually reduced somewhat as the diameter is increased. In Fig. 3 is shown the relationship between the angular speed and the maximum desirable rotor diameter.

The Choice of Rotor Steel.

The obvious requirements of the rotor steel are that the permeability should be as high as possible and that mechanically the material should be suitable for the duty. The exciting energy required to drive the flux through the rotor varies considerably according to the relative proportions of the design and the performance of the machine. In an average case, however, it may be of the order of 15 to 20 per cent of the full-load excitation. It is important, therefore, that the permeability should be as high as possible consistent with

* *Journal I.E.E.*, 1911, vol. 47, p. 562.

satisfying the mechanical requirements. As already mentioned, the maximum stress in the rotor is not great, and the designer has apparently a wide choice of steels. The choice, however, becomes rapidly narrowed down when it is stipulated that in addition to having the necessary strength the steel must have capacity to withstand shock and fatigue, be tough, ductile, of the kind that is least likely to have flaws, the best suited to use for a large forging, and above all be dependable in the highest degree. Beyond doubt, the steel that best fulfils these requirements is an oil-treated carbon steel. Such a steel, containing about 0·38 per cent carbon, after oil treatment has an ultimate strength of 38 tons per square inch, a yield point of 22 tons, an elongation of 22 per cent on 2 inches, and a contraction of area of 40 per cent. It is of the class of steel that is used for such purposes as railway axles, and has to resist shock and fatigue and be dependable above everything, and is therefore admirably suitable for alternator rotors. The permeability of this steel is quite good, as shown in Fig. 4.

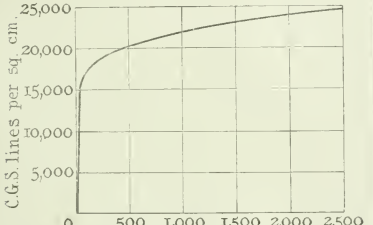


FIG. 4.—Magnetization curve of medium carbon steel (oil-hardened) for turbo-alternator rotors.

It is usual to express the factor of safety in terms of the ultimate strength—which is not quite logical, since it is the yield of the material that marks the limit of safety and not the actual fracture. The ratio between the yield point and the ultimate strength differs considerably with different classes of steel, and varies a little even with any particular steel according to the nature of the heat treatment. For example, with a mild carbon steel in the annealed state the yield point may be about 50 per cent of the ultimate strength, and after oil hardening may be increased to 60 per cent. With a high-tensile nickel-chrome steel the ratio may be as high as 85 per cent, and with cold-drawn steel wire as high as 95 per cent. For this reason the author is of the opinion that the factor of safety should always be expressed in terms of the yield point. It would be better still to express it in terms of the elastic limit, but the difficulty is that the elastic limit cannot be determined in a tensile test and can really only be found by a long series of tests under reversals of stress. The yield point is defined as being the stress at which there is a complete yield of the material that is observable to the eye. The true elastic limit is reached at some lower stress, when incipient but not measurable permanent set is caused. In stipulating the factor of safety the nature of the duty has to be considered, and the value that would be safe for a steady load would be quite unsafe for a rapidly fluctuating load. As we have seen, the maximum stress in the solid forged rotor is in the teeth. The stress is unidirectional and constant, and a factor of safety of 2 to 1 on the yield point is to be regarded as satisfactory with a dependable steel. With this factor of safety the maximum permissible tooth stress with the quality of steel suggested is 11 tons per square inch. With a well-proportioned rotor having a diameter of 31 inches—which, as explained, is approaching the largest diameter that it is desirable to employ for a normal speed of 3,000 r.p.m. with the type of rotor now being made—the maximum tooth stress at 20 per cent overspeed is about 9½ tons per square inch. It will be seen, therefore, that the quality of steel suggested well meets the requirements. It might be thought that, if a higher stress could be allowed, a narrower tooth could be provided and there would be more room for rotor copper and consequently a greater output. The question of the tooth density, however, has to be considered. There must be some saturation in an alternator to give it magnetic stability. There are cases on record of alternators that would not operate satisfactorily due to insufficient saturation, the excitation being overwhelmed by the armature reaction at changes of load. With a turbo-alternator the necessary saturation must be provided in the rotor teeth—that being the only part of the machine where a high density can be arranged or is permissible. On the other hand, if the saturation is carried too far, the loss in the teeth becomes excessive. With a normal 5,000-kw. alternator at 3,000 r.p.m. the exciting energy required for the rotor teeth is of the order of 10 per cent of the full-load excitation. With a badly proportioned rotor the loss may be as high as 20 per cent. In general, it will be found that with a stress of about 10 tons per square inch the corresponding tooth density is as high as it is desirable to employ, and the oil-hardened carbon steel therefore satisfies the electrical as well as the mechanical requirements.

It is sometimes suggested to employ an alloy steel for the rotor, but there is very little gain, if any, in doing so with the objects immediately in view, and on the other hand there are pronounced disadvantages. For instance, if an alloy steel were employed with the object of being able to use a smaller tooth to give increased winding space, it would be found in most cases that the increased magnetization loss, due not only to the higher tooth density, but also to the lower permeability, would more than offset the gain due to the increased copper space. There is the objection to using an alloy steel that for a large rotor forging it is inherently not so reliable, there being a greater probability of internal flaws being present. A hole should always be bored through the forging when an alloy steel is used, and the bore should be carefully examined to see that there are no internal flaws. As already

explained, the effect of the hole is more than to double the hoop stress, so that the body of such a rotor actually would be weaker than if a carbon steel were used.

An interesting case came to the author's notice a few years ago of a rotor forging breaking just where the shaft merged into the body of the core. The steel used was 3½ per cent nickel having a yield point of 29 tons and an ultimate strength of 46·5 tons per square inch, and an elongation on 2 inches of 22 per cent. It was found that a huge internal cavity had been caused by the operation of forging, as shown in Fig. 5. The corresponding part at the other end of the rotor was cut open, and although there was no cavity the steel was in a highly stressed and weakened condition. Insufficient care in forging might cause weakness in this way with any steel, but it is much more probable with an alloy steel than with a carbon steel. In another case that came to the author's notice a high carbon steel was employed having the composition of 0·61 carbon, 0·59 manganese, and 0·23 silicon, and the tensile properties of ultimate strength 49 tons per square inch, yield point 22 tons to the square inch, elongation on 2 inches 18 per cent, and reduction of area 32

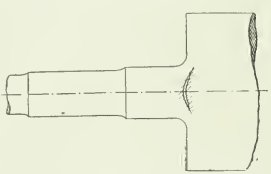
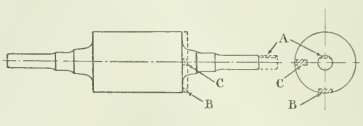


Fig. 5.—Forging defect in high-speed rotor.

per cent. After being in service for 3½ years the forging failed with a fatigue flaw in the neck of the journal. A micro-examination showed that the steel had not been properly heat treated and had a large grain size. Such a steel, and more particularly in the absence of correct heat treatment, is not at all suitable for a high-speed rotor.

The use of improper steels of this kind and bad mechanical design—with which not even a good steel could stand—have led to a number of failures, which have given rise to the feeling, amongst those not familiar with the conditions, that the solid forged rotor is less reliable than the built-up design. For the onerous conditions of high-speed work, it is not good enough to use a block of any kind of steel in any state of heat treatment and to machine it without regard to fundamental mechanical requirements. There is no doubt that provided the right kind of steel is used, correctly forged and correctly heat treated, and that the mechanical design is sound, the solid forged rotor is by far the best construction, and the author has never heard of a single failure when these conditions have been observed. The only justification for the built-up construction is for small rotors and when high-grade forgings are not obtainable, and for single-phase work.

The forging for the turbo-alternator with its radial stress presented a new condition to the steel maker; and, not because there was any real difficulty with it but because it was a new requirement that they had not investigated, some makers would not undertake the work. With ordinary care in forging there is no difficulty in giving the required radial test. The tensile strength radially is very much the same as in the longitudinal direction, but the elongation is usually lower. Three tests should be made from each forging—one from the shaft end, one tangentially from the core, and one radially from the core, as shown in Fig. 6. With an



Part	Yield Point, Tons per sq. in.	Ultimate Tons per sq. in.	Elongation on 2 in.
Longitudinal, A ..	22·5	38·5	28 per cent
Tangential, B ..	22·5	38	27 ,,
Radial, C	22	37·5	22 ,,

Fig. 6.—Tests from an oil-hardened carbon-steel rotor.

oil-hardened carbon steel containing about 0·38 carbon the results shown in the table in Fig. 6 may be expected. The figures given are actual results; the makers' guarantees with regard to elongation, and particularly in the radial direction, would be somewhat lower.

Limit of Forging Size.

There are limits to the size of forging that a steel manufacturer can undertake. There is the inherent limitation due to the rate of cooling of the interior of a large mass of metal. The size of the crystals and hence the properties of the steel are profoundly influenced by the rate at which it cools. If the mass of steel were unduly great, the cooling of the interior would be so slow that the mechanical quality in consequence could not be made to conform to the necessary requirement. With the forgings for turbo-alternators of the sizes so far considered the problem does not arise, and the limitations are the manufacturer's facilities for casting an ingot sufficiently large and the capacity of his forging plant. Nothing definite, therefore, can be laid down as to the largest size of rotor that can be produced in a single piece, but it is in the neighbourhood of 50-in. diameter. That is to say, for all outputs so far contemplated at 3,600, 3,000, and 2,400 r.p.m. a single forging can be obtained, and also for all except very large ouputs at 1,800 and 1,500 r.p.m. For very large outputs at 1,800 r.p.m. and lower speeds a single forging may not be satisfactory. In such cases the soundest construction is to forge a hollow cylinder with a shaft extension attached to each end, or better

still carried on a through shaft as shown in Fig. 7. Forging the cylinder on a mandril does work on the steel and gives it its best qualities on the inner periphery where the hoop stress is a maximum. Moreover, in quenching, the oil has access to the bore and the maximum benefits of the heat treatment are conferred at the part of maximum hoop stress. With such large rotors there is no difficulty in so proportioning the belt of metal between the bottom of the slots and the bore

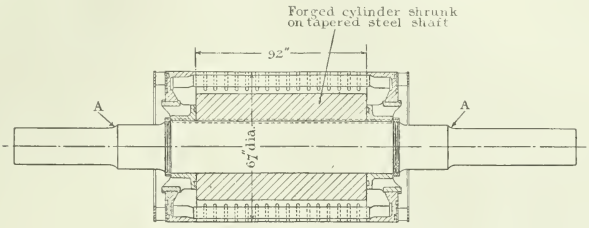


FIG. 7.—Rotor for a large 1,000-r.p.m. turbo-alternator.

that the hoop stress is kept down to a satisfactory value. For very large rotors this construction therefore constitutes an excellent arrangement.

THE SHAFT DESIGN.

In determining the design of the shaft it is most important that the proportions should be such that the curve of deflection is smooth and free from any sudden change. The forces due to the rotor weight cause

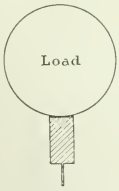


FIG. 8.—Showing how a beam can be weakened by adding to its section.

the steel to yield elastically until the reacting force balances the weight. So long as the duty on the individual crystal is within its capacity the structure is safe, but if that limit is passed the crystal deforms by slip taking place along the cleavage planes. The excessive burden falls on to the neighbouring crystals, and they in turn fail, and so on until fracture is caused. For the structure to be safe, therefore, not only must the area of the steel be adequate for the load to be carried, but the proportions must be such that it is free to yield elastically to exert its reactive force without any local over-stress being caused. If the design is such that there is a tendency for some part of relatively small area to resist the general deflection, that part may be overstressed and failure may result. An example of such a case is given in Fig. 8. The beam with the fin projection and the load can be so proportioned that before the beam has deflected sufficiently to give the necessary reaction to support the load the crystals at the bottom of the rib are overstressed. Failure, therefore, would result with such a construction, whereas the beam without the fin would carry the same load satisfactorily. Where there is an abrupt increase of diameter in a shaft, the conditions are somewhat but not exactly similar. Just where the increase of diameter takes place the shaft portion is under stress and is yielding elastically. The flow of stress into the larger diameter is somewhat gradual, and the face of the metal that is rising at right angles from the smaller diameter to the larger diameter carries little or no stress, and there is therefore in intimate contact steel that is elongating

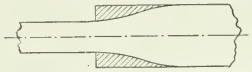


FIG. 9.—A sudden increase in diameter may be regarded as adding metal to a gradual increase, and is analogous to the weakening effect of adding a thin rib to a beam as shown in Fig. 8.

and compressing elastically and steel without stress, and great weakness is thus caused. A gradual change of diameter represents a normal design, and a sudden change is to be regarded as adding metal to the normal design as shown shaded in Fig. 9. The added metal tends to prevent the normal elastic deformation and has inadequate strength for the purpose. In such a case the tendency to fail is often increased by the crystals at the junction of the two diameters being torn and weakened by the action of the cutting tool.

In Fig. 21 is shown a case of failure that came to the author's notice a few years ago. It will be noticed that there is a very sudden increase of diameter between

the bearing journal and the large oil baffle that is formed solid with the shaft. After 11 months' running the shaft broke in the position shown. Not only was the design thus most unsound, but the material was unsuitable, being of a high-carbon steel that had not been heat treated and having a very coarse grain size.

Abrupt changes in the curve of deflection must therefore be carefully avoided. The shaft should be gradually stepped to avoid any sudden increase of diameter, and wherever a change of section occurs a carefully formed radius should be provided. Gauges to check the accuracy of the radii in important places, such as in the neck of the journals, should form part of every shop inspector's equipment. In addition to being carefully formed, the radii should be given a fine finish and good polish. It has been shown by Sir George Beilby* that the effect of polishing is that the superficial molecules become mobile and form a thin viscous layer with surface tension analogous to that of liquids. After a very short period the layer loses its mobility and solidifies into a vitreous amorphous state, forming a very strong cementing material. On the other hand, if the surface is left rough the surface crystals are torn and weakened, and the conditions are favourable for fatigue to develop.

The need for avoiding abrupt change of section applies to all parts of the rotor, and at the junction between the teeth and the body of the rotor ample radii should be provided.

Alternating Stress.

The maximum reverse stress in the rotor is in the neck of the bearing journal at the part marked "A" in Fig. 7. The weight of the rotor puts the figure at the top of the shaft into compression and at the bottom of the shaft into tension. As the shaft turns round, the stress changes from tension to compression. In the case of a 3,000-r.p.m. alternator the number of reversals per day is 4,320,000; that is to say, the number of reversals daily is equal to what investigators into the subject of alternating stress have regarded as a complete endurance test.

Failure from fatigue is really the same as failure under a simple tensile test, in so far as it is the result of the overstressed crystals yielding plastically by slip along the cleavage planes. The essential difference is that failure by fatigue is relatively very slow and is localized, not being accompanied by any general yield of the material.

The investigations of recent years have thrown some light on the reason for steel failing under an alternating stress that could have been carried indefinitely if applied constantly. Ewing, Humphrey, and Stanton have discovered that the failure generally starts in the ferrite grains, which consist of iron in its crystalline and therefore softest state. The stability of the ferrite is much less than that of the aggregate, so that stress insufficient to strain permanently the aggregate would be more than sufficient to break down the ferrite grains if the stress had access to them. Sir George Beilby† discovered by studying the vibrations of cold-drawn reeds before and after annealing, that although the crystalline phase is more elastic than the amorphous phase, yet the amplitude of vibration is greater in the latter state. It is reasonable to expect, therefore, that when an aggregate composed of two phases is subjected to rapidly alternating stress, the harder element with its greater amplitude will cause the softer element with its less amplitude to carry an undue proportion of the stress.

Under a simple tensile test, as the load is increased the first crystals to fail are those that are the worst circumstanced with regard to size and the orientation of the gliding planes. These crystals deform plastically, and the stress is therefore to a certain extent removed and becomes more distributed over the aggregate. Such a point marks the true elastic limit, and the stress has to be increased appreciably before there is the general deformation of the crystals as a whole that is observable to the eye, known as the yield point.

That a steel crystal has strength after permanent deformation is explained by Sir George Beilby * to be due to minute particles being torn away from the contact surfaces, of a lower order of magnitude than any crystal unit, that form an amorphous cement stronger than the crystals themselves. The action is analogous to what happens when the surface of metal is polished as explained above. With any normal metal it is found that fracture always takes place along the cleavage planes of the crystals themselves, and not by the failure of the amorphous cementing material that holds them together. The presence of this amorphous material produced by the rubbing along the gliding planes may quite well, therefore, have the effect of making the crystal stronger after yielding than it was before. This explanation agrees with the fact that under a tensile test a greater stress is required to rupture the material than was necessary to cause the yield.

The conditions necessary for failure by fatigue are that the real elastic limit of the steel is exceeded but that the yield point is not reached. If the elastic limit were not reached, the metal would not fail however many reversals may be made; and if, on the other hand, the yield point were reached the failure would take place by ductile elongation before fatigue developed. After the first local yielding of the worst circumstanced crystals, if the load is kept constant nothing further happens and the steel would carry the load indefinitely. If, however, the stress is quickly reversed, the slip of the crystals will be reversed, the movement being considered to be facilitated by the newly produced amorphous material being in a temporarily mobile state. At each reversal there is corresponding slip along the gliding planes, and more of the amorphous material is produced until the crystal is exhausted and failure results. This process then begins in other crystals and spreads until complete failure is caused.

It was thought by some of the earlier investigators into the subject of reverse stress † that the liability to fail increased with the speed of reversal. It is now

* *Proceedings of the Royal Society*, vol. 72, p. 218.
† *Journal of the Institute of Metals*, 1911, vol. 6, p. 5.

* *Journal of the Institute of Metals*, 1911, vol. 6, p. 5
Osborne Reynolds and J. H. Smith: *Philosophical Transactions of the Royal Society*, 1902.

generally agreed that these investigators were misled by the peculiarities of the type of testing machine they employed. It is fairly certain that failure by fatigue is independent of the speed of the reversals unless the speed be very low or very high. It is well known* that after plastic deformation if steel is allowed to rest the strength increases. This quality, however, is without value in shafts, since the period of rest required is a matter of days unless hastened by the action of heat. On the other hand, if the speed is very high the time that the load is applied may be insufficient for yield of the material to take place. The time required for a crystal to deform is appreciable whatever stress may be applied, and it is to be expected that if the stress is applied for a very brief period only there may be insufficient time for the steel to deform plastically, although the magnitude of the stress may

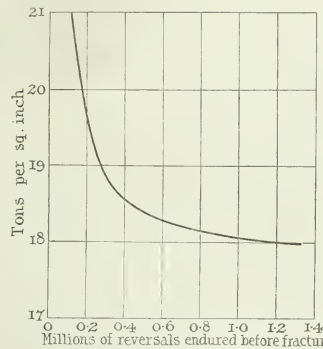


FIG. 10.—Endurance tests of oil-hardened carbon steel with 2,000 alternations of stress per minute.

be sufficient to cause rupture if applied steadily. Dr. B. Hopkinson has shown† that steel wire having a yield point of 17·8 tons per square inch and an ultimate strength of 28·5 tons per square inch can carry a load of 33½ tons if it is applied for about only 1/1,000th part of a second. He has also shown‡ that with reversals at the rate of 7,000 per minute the resistance of metals to reversals of stress is appreciably greater than at low speeds. The speed at which this property becomes of value has not been clearly determined. Dr. Stanton§ states that with tests he made at speeds of from 100 to 2,200 reversals per minute there was no evidence that the rate of reversal had any effect on the resistance to failure. It is probable that at the normal running speed of the high-speed alternator the alternations of stress have a maximum effect, since the speed is not sufficiently high for it to have any ameliorating effect, and on the other hand the great speed tends to bring unforeseen load into play. It becomes necessary, therefore, to give very careful attention to the design in this respect.

When making tests under alternating stress the procedure is to apply a load that it is known will produce failure and to note the number of alternations before breakdown results. The test is repeated with a similar specimen under a reduced load, and so on until the load is found under which the specimen will not break however many alternations may be made. If the results are plotted the curve is parabolic, as shown in Fig. 10, the horizontal asymptote showing the stress with which an indefinite number of reversals would not produce fracture.

The fatigue failure is so insidious in its action, and so many unforeseen factors may be present to contribute to it, that a big margin of safety is desirable. For instance, the calculated stress may be much exceeded by a slight error of alignment, and the possibility of minute irregularities or flaws must be considered, which for any other condition of loading would be without practical effect. Moreover, the torsional stress which is a contributing factor may have its normal value much exceeded by a short-circuit. Further, in expressing the factor of safety in terms of the yield point it is to be remembered that the true elastic limit, which, as explained, determines fatigue failure, is considerably lower than the yield point. It has been shown by Ewing and Humphrey,* by observing the creation of slip bands under alternations of stress, that the true elastic limit of a carbon steel may be only 52 per cent of the yield point. Taking all these factors into consideration, it is the author's opinion that the combined calculated stress in the neck of the journal should not exceed 7½ per cent of the yield point of the steel. With the high bearing duties of to-day—journal speeds of 6,500 feet per minute being quite satisfactory—there is no difficulty in keeping within this factor of safety.

Heat Treatment.

The rate at which steel cools has a profound effect on its structure and physical properties. The effect of cooling steel rapidly is much debated by metallurgists, and there is no general agreement as to the precise effect. It has been established that steel has the characteristic of allotropy and its properties vary according to the allotropic form in which it exists. As with most substances, allotropy in steel is a function of temperature with normal cooling, as is shown by the recalescence points in the time-temperature curve. The change, however, from one allotropic form to another requires time, and rapid cooling as is brought about by quenching in oil or water considerably influences the degree of the change. Under a tensile test the performance of steel is apparently little affected by the crystal size,† but the resistance to shock and

* MUIR: *Philosophical Transactions of the Royal Society*, 1902, vol. 103 A.
† *Proceedings of the Royal Society*, vol. 74, p. 498.
‡ *Ibid.*, vol. 86 A.
§ *National Physical Laboratory Report*, 1910.

* *Philosophical Transactions of the Royal Society*, vol. 200 A, p. 241; see also STANTON and BAIRSTOW: *Proceedings of the Institution of Civil Engineers*, 1905–6.
† SHARPY: *Revue de Metallurgie Memoires*, 1910, vol. 7, p. 656.

the capacity to withstand reversals of stress are directly influenced. The greater the temperature to which steel is heated the longer it is maintained at high temperature, and the more slowly it is cooled the greater is the crystal size and the less dependable is the steel. A medium carbon steel of the kind suggested for the rotor has its yield point increased about 30 per cent by oil hardening. It is seen, therefore, that the correct oil treatment of steel very considerably improves its tensile strength, and also puts the steel generally into better condition and makes it more reliable. For these reasons it is very desirable that all alternator

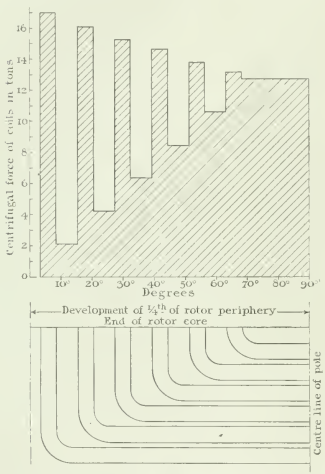


FIG. 11.—Showing the variation in the centrifugal force of the rotor coils in the circumferential direction of a 5,000-kw. 3,000-r.p.m. alternator with 31-in. diam. rotor (calculated at 20 per cent above normal speed).

rotor forgings should be oil treated. The approximate treatment of the steel in question would be to immerse in oil at about 800° C. and temper at about 550° C., the treatment varying according to the carbon content. The heat treatment should be carried out after the forging has been rough turned. Some distortion of the forging is unavoidable in the oven, and the rough-turned dimensions should be somewhat greater than the finished sizes. In an average case the allowance on the diameter should not be less than 0·25 inch.

Rotor End Bells.

As already indicated, the most highly stressed part of the rotor is in the end bells retaining the rotor end windings, and the design of the bells, therefore, requires the most careful attention. In the case of a 5,000-kw. alternator at 3,000 r.p.m. with a 31-in. diameter rotor, at the overspeed of 20 per cent above normal the centrifugal force exerted by the windings at each end of the core is about 820 tons. If to this is added the centrifugal force of the bell itself, the total centrifugal force at each end is about 2,000 tons. For such enormous forces it is obvious that the material employed must be very high grade.

In the earlier days of the turbo-alternator, steel binding wire was frequently used. The material itself is satisfactory, since it is reliable and has very great strength—an ultimate strength of over 100 tons per square inch being usual, with the yield point not much lower. Two great disadvantages of using binding wire are the difficulty of maintaining a good balance and the necessity for completely re-winding the band if the rotor windings have to be examined. For these and other reasons wire banding is not used on modern turbo-alternators.

In considering the choice of material for the end bells the designer naturally has preference for non-magnetic material. With the end bell registering on the rotor core, if it is magnetic it offers a direct leakage path of considerable area from pole to pole, and has an appreciable effect in reducing the useful rotor flux.* The leakage has a constant value with a given diameter and excitation, and the percentage value is therefore less the longer the rotor. In the case of an average 5,000-kw. 3,000-r.p.m. alternator at full load the leakage is of the order of 10 per cent of the excitation energy. Before steel bells were tried it was thought that there might be heating in them due to leakage flux from the stator, but experience shows that such is not the case, the reason being that any such flux rotates synchronously with the bell. It was thought also that for solid bells of any material such a large mass of metal close to the end of the stator core might cause undue heating due to eddy currents induced by the action of the flux swinging from tooth to tooth. Such, however, is found not to be the case, or if there is any such action it is not important in degree.

The magnetic end bells appear to have one rather remarkable effect in causing great heating in some cases at the ends of the stator core when running on short-circuit. In one case that came to the author's notice of a 5,000-kw. 1,500-r.p.m. alternator with steel end bells, when running on short-circuit the stator end plates and the laminations in the immediate neighbourhood became very hot; embedded thermo-couples placed about 2 inches from the end of the core showed a rise of 150 degrees F. Thermometers placed against the back of the core also showed a high temperature rise in the immediate vicinity of the end plates and a low temperature elsewhere. On full load the end plates were quite cool, and the temperatures shown by the thermometers and thermo-couples were quite normal. In two cases of 5,000-kw. alternators at 3,000 r.p.m. there was similar heating at the ends of the stator core in a still more marked degree. Embedded thermo-couples placed $\frac{1}{2}$ inch from the end of the core showed a rise of 250 degrees F. after an

* R. G. JAKEMAN, *Electrician*, 1915, vol. 75, p. 765.

hours run on short-circuit. The temperature rise of the cast-iron end plates was about 120 degrees F., showing that the greatest heating was in the laminations themselves.

The author suggests that this phenomenon is probably due to the steel end bells. When a short-circuit test

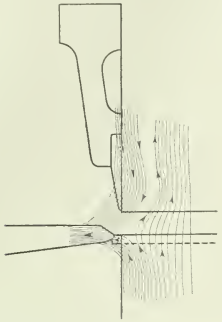


FIG. 12.—Stator leakage into steel end bell on short-circuit.

is made with an alternator, the excitation is increased until the current reaches its full-load value. The stator current lags almost 90°, and the reaction is in phase with the rotor flux and in opposition to it. Most of the rotor excitation is required to overcome the

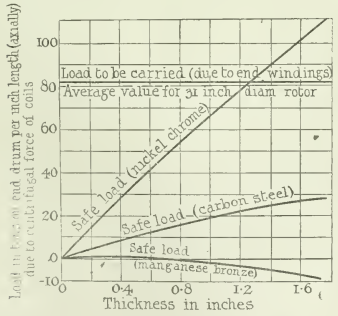


FIG. 13.—5,000-kw. 3,000-r.p.m. alternator (calculations made at 20 per cent above normal speed).

stator reaction. The leakage into the end bells weakens the rotor magnetism at the ends of the core, and quite conceivably the stator reaction may overcome it and there may be an appreciable flow of reverse flux between the ends of the stator and the end bells. The reaction between these fluxes flowing in different directions at the ends of the stator core may quite well cause some of the reverse flux to flow obliquely through the plates

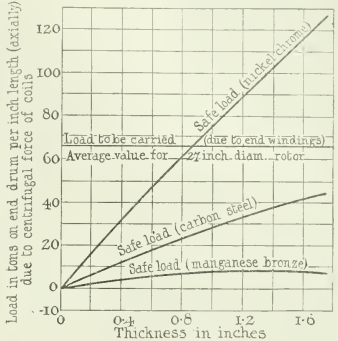


FIG. 14.—3,000-kw. 3,000-r.p.m. alternator (calculations made at 20 per cent above normal speed).

and so cause heavy eddy-current loss. Probably also there is a small leakage of flux into the stator end plates. The effect is indicated roughly in Fig. 12. Since the effect, whatever the explanation may be,

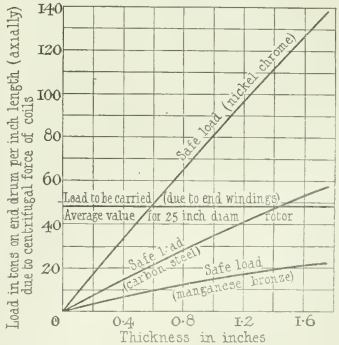


FIG. 15.—2,000-kw. 3,000-r.p.m. alternator (calculations made at 20 per cent above normal speed).

does not occur under any running condition, it is of little importance. It may, however, quite upset the method some makers have of forecasting the temperature rise on load from light-load tests—with which one

factor is the temperature rise on short-circuit. Moreover, it may cause the designer to attribute to eddy-current loss in the copper a loss that is due to something else altogether.

Of the non-ferrous metals available for making end bells the best is a high-grade manganese-bronze. Good material of this kind has an ultimate strength of about 44 tons per square inch, a yield point of 22 tons per square inch, and an elongation of 20 per cent. The real elastic limit of the material as shown by its behaviour under reversals of stress is lower with regard to the yield point than with a good steel. For this reason the author is of opinion that the maximum stress should not exceed 45 per cent of the yield point. In Figs. 13, 14, 15, 16 and 17 are shown the average load

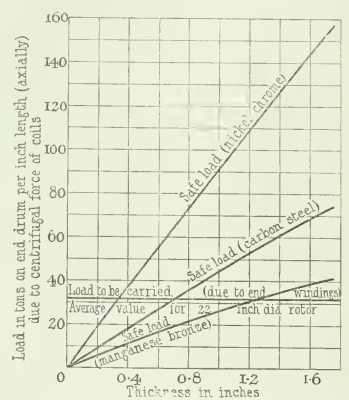


FIG. 16.—1,500-kw. 3,000-r.p.m. alternator (calculations made at 20 per cent above normal speed).

per axial linear inch that the end bell has to carry due to the centrifugal force of the end coils for rotors for 3,000 r.p.m. of 31-in., 27-in., 25-in., 22-in. and 20-in. diameter respectively, calculated at the overspeed of 20 per cent above normal. The bottom curve in each case shows for various thicknesses the load that the manganese bronze can carry in addition to itself with a stress equal to about 45 per cent of the yield point—i.e. 10 tons per square inch. With a 31-in. diameter rotor it will be seen that the manganese bronze can only just carry itself when its thickness is varied from zero up to about 0·7 inch. If the thickness is further increased, the stress is increased and exceeds the safe value for the material. With the 27-in. diameter rotor the manganese bronze has a maximum load carrying value when the thickness is about 1·5 inch, but it can then carry only about 8·5 tons per linear inch out of about 66 tons that have to be carried. With the 25-in. diameter rotor with a bell thickness of 1·7 inch the bronze can carry only about 22 tons per inch, against 48 tons to be carried. For the 22-in. diameter rotor the bronze bell is satisfactory if it is given a thickness of 1·25 inch, and for a rotor of 20-in. diameter it is satisfactory when 0·9 inch thick. These diagrams thus show clearly the extent to which the material may be used—i.e. that it is satisfactory for 3,000-r.p.m. rotors up to about 22-in. diameter.

Figs. 15, 16, and 17 show that oil-treated carbon steel can be used satisfactorily for the end bells of rotors up to about 25-in. diameter at 3,000 r.p.m., but not for any larger diameters. The curves for the carbon and for the nickel-chrome steel are based on working at 50 per cent of the yield point of the material, the carbon steel having a yield point of 22 tons per square inch and the nickel-chrome steel 40 tons per

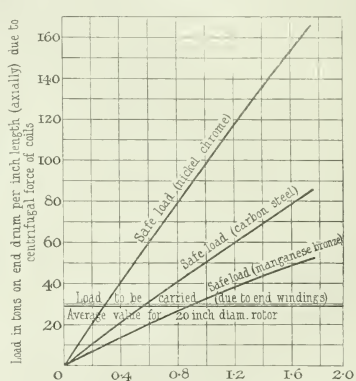


FIG. 17.—750-kw. 3,000-r.p.m. alternator (calculations made at 20 per cent above normal speed).

square inch. Even for the smaller diameters, however, there are advantages in favour of using nickel-chrome steel. For instance, for the 25-in. diameter rotor (Fig. 15) it will be seen that a thickness of 1·43 inch is necessary for carbon steel, whereas with the nickel-chrome steel 0·6 inch would be sufficient. The magnetic leakage with the nickel-chrome steel would be much less and the flow of the ventilating air into the air gap would be less restricted. For rotors more than 25 inches in diameter nickel-chrome steel should always be used. Nickel-chrome steel containing about 3·5 per cent nickel, 0·5 per cent chromium, and 0·25 per cent carbon has an ultimate strength of about 50 tons per square inch, a yield point of 40 tons, and an elongation of 18 per cent on a 2-in. test-piece, and a reduction of area of 50 per cent.

Of the non-magnetic steels 25 per cent nickel is the only kind of which the use has been suggested for end bells. This material, having the approximate

composition of 25 per cent nickel, 4 per cent chromium, and 0·36 per cent carbon, has the ultimate strength of about 42 tons per square inch and an elongation of 40 per cent on 4 inches. The observed yield point is about 25 tons per square inch, but the real elastic limit is very low. With a careful test the extensometer

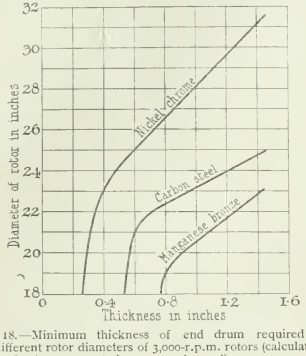


FIG. 18.—Minimum thickness of end drum required for different rotor diameters of 3,000-r.p.m. rotors (calculations made at 20 per cent above normal speed).

shows a slight permanent set with a loading as low as 15 tons per square inch, and of course the real elastic limit must be at a still lower stress. The steel is not difficult to machine and can be drawn satisfactorily into wire. It is difficult to forge, however, there being a marked tendency for the red-hot billet to crack under the hammer. It is annealed by quenching in water at about 1,450° F. The steel is not magnetic, for the reason that at ordinary temperatures it exists in the same allotropic form as does iron heated above its highest recalescence point—i.e. about 900° C. If the non-magnetic steel is immersed in liquid air it is changed into the same allotropic form as is iron cooled below about 760° C., and it becomes magnetic. 25 per cent nickel steel is quite unsuitable for high duty, and manganese bronze, with its higher yield point and more reliable qualities, should always be used in preference.

Hadfield's manganese steel is quite unsuitable for end bells, having a very low yield point and having the remarkable quality that, although really soft, deformation makes it extraordinarily hard and it cannot be machined. Another non-magnetic steel also unsuitable is that due to Carpenter, Hadfield, and Longmuir, containing 19·91 per cent nickel, 0·41 per cent carbon, and 0·96 per cent manganese.

Magnetization appears to be due to the arrangement of the atoms in the molecule, or of the molecules themselves, and is not a property peculiar to the atoms of those elements that are magnetic. There is the effective proof furnished by Heusler * that an alloy containing only non-magnetic elements may be magnetic. He produced such an alloy composed of 60 per cent copper, 26 per cent manganese, and 14 per cent aluminium, all of which elements are non-magnetic. On the other hand, alloys containing a large percentage of iron may be non-magnetic—such as 25 per cent nickel having about 70 per cent of iron, and Hadfield's Austenitic manganese steel containing about 88 per

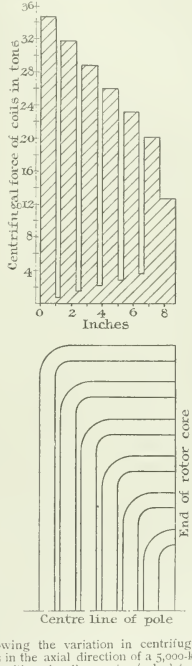


FIG. 19.—Showing the variation in centrifugal force of the rotor coils in the axial direction of a 5,000-kw. 3,000-r.p.m. alternator with 31-in. diam. rotor (calculated at 20 per cent above normal speed).

cent of iron. Heusler's magnetic alloy undergoes allotropic change when quenched at 400° C. and becomes non-magnetic.* Hadfield's manganese steel undergoes allotropic change when it is deformed and becomes magnetic.† The non-magnetic steel of Carpenter, Hadfield, and Longmuir behaves similarly.‡

* "Über die Ferromagnetischen en Eigenschaften von Legierungen Unmagnetischer Metalle," Marburg, 1904.

* *Proceedings of the Royal Society*, vol. 77 A, p. 256; see also vol. 76 A, p. 271.

† *Journal of the Iron and Steel Institute*, vol. 89, p. 132.

‡ Seventh Report of the Alloys Research Committee, *Institution of Mechanical Engineers*, 1905, p. 949.

Whereas oil treatment is desirable with carbon steel, with nickel-chrome it is indispensable. As with the rotor, the end-bell forgings should be rough turned and then be heat treated.

As an alternative to the magnetic and non-magnetic end bells, there may be considered the question of a composite end bell. The centrifugal force of the coils varies in the axial direction, being least at the core end and a maximum at the other end. In Fig. 19 is given a curve showing this variation in the case of a 26-in. diameter rotor for 3,000 r.p.m. with six concentric rotor coils. It will be seen that the load on the end bell is appreciably lower near the stator than the average value. For a 25-in. diameter rotor, for

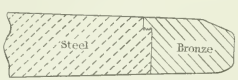


FIG. 20.—Composite end bell for high-speed rotor.

which a manganese-bronze bell could not be used, it would be permissible to employ a composite bell of steel with a relatively narrow band of manganese bronze next to the core. Such a bell is shown in Fig. 20. The saving in magnetization loss with such a construction as compared with the all-steel bell may be of the order of 50 per cent. The author's view is that the all-steel nickel-chrome end bell represents the preferable construction, and that the composite bell should be employed only in exceptional circumstances. With the composite bell it is important to remember that the elasticity of manganese bronze is about 20,000,000 lb. (inch units) against 29,500,000 lb. for steel; that is to say, for a given stress the manganese bronze stretches (elastically) 47½ per cent more

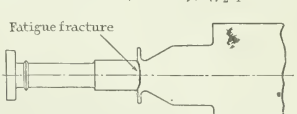


FIG. 21.—Solid forged rotor with defective shaft design.

than steel. It is important for this reason that the manganese-bronze ring should be registered on the steel ring, and not under it, so that it is free to open. If the bronze were registered under the steel, the projecting lip would prevent the bronze opening sufficiently (elastically) to carry its share of the load, and the lip might be overstressed. The correct construction is shown in Fig. 20. The author has heard of failures due to this obvious precaution not being taken.

The usual design of end bell is a cylinder registering on the rotor core at one end and on a disc shrunk on to the shaft at the other. In the case of a 5,000-kw. 3,000-r.p.m. alternator the cylinder opens about 0·03 inch in diameter. It is not possible to give the cylinder sufficient initial tension by press fit to prevent it opening in this way. The tendency of the coil loading (see Fig. 11) is to make the cylinder become elliptical, but since there is nothing to centre it definitely it may move bodily out of centre by the amount it opens radially. The vibration with some alternators that cannot be corrected completely is probably due to this cause in some cases. The author is very strongly in favour of making the cylinder and the end disc down to the shaft in a single piece as shown in Fig. 23; the bell is thus definitely centred and eccentricity is prevented. An additional advantage of this design is that it is not necessary to register the bell on the rotor core and an appreciable gap can be provided between the core and the bell, so reducing the magnetic leakage. The short length of coil between the core and the bell is supported by extending the slot wedge and by regis-

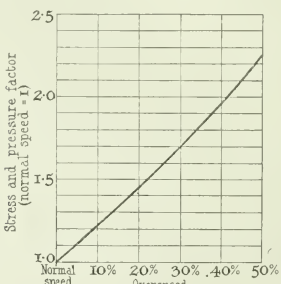


FIG. 22.

tering the end of the wedge under the bell. Another advantage that may be obtained with this construction is to make the seating on the shaft larger in diameter than the slip-rings, so that the end bells may be removed for examination or repair of the windings without interfering with the slip-rings or the connections to them. The construction also has the advantage of very considerably strengthening the cylinder at the end where it is most heavily loaded. In Fig. 18 is shown the average thickness of end bell required for rotors of various diameters for manganese bronze, carbon steel, and nickel-chrome steel.

VENTILATION.

The various systems of ventilation that have been tried at various times have now settled down roughly to two distinct types—axial and radial. The advantages of the axial system are that the omission of the radial ducts shortens the machine and that the rotor may be separately and positively ventilated. The disadvantage of this system is that there is an appreciable difference of temperature between the two ends of the machine. The temperature difference may be

reduced somewhat by arranging the flow of air through the rotor and stator in opposite directions. With the radial system the temperature rise can be kept almost uniform from end to end, but there are the disadvantages that most useful material is removed from the rotor in forming the radial ducts and that the rotor ventilation is not positive. The flow of air through the rotor is induced only by the natural fanning effect of the radial ducts, and the flow is opposed by the pressure in the gap set up by the fans. With large machines the air velocity through the stator has to be made high for the necessary volume of air to

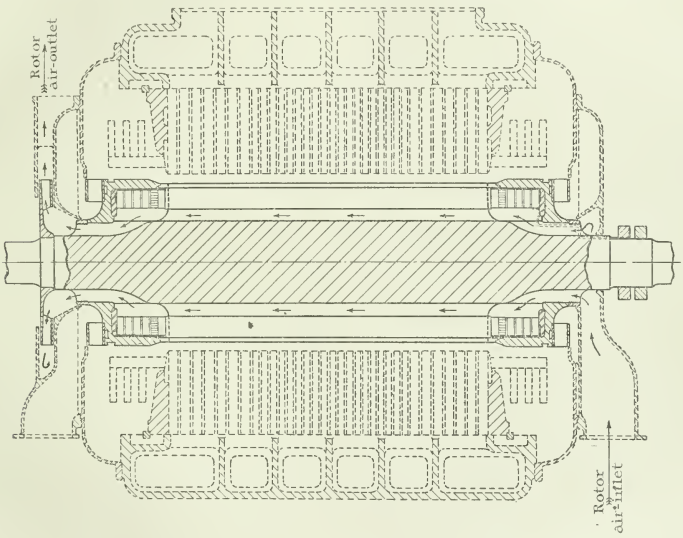


FIG. 23.—Turbo-alternator with axially-ventilated rotor and radially-ventilated stator.

flow, and pressure equal to 6 inches or 7 inches of water has to be set up by the fans. At the ends of the rotor such a pressure quite overcomes the rotor fanning effect, and the discharge from the rotor ducts must be prevented if not actually reversed. It is probably only towards the centre of the core, where the air-gap pressure is reduced, that there is any appreciable flow of air from the rotor.

The author considers the ideal system to be to have radial ventilation for the stator with independent axial ventilation for the rotor as shown in Fig. 23. The air for the rotor and stator is kept quite separate and the volume and temperature rise of it can be separately measured. By varying the rotor fan the volume of air flowing through the rotor can be regulated to give the exact volume required. The omission of the rotor axial ducts gives the designer liberty to work to the tooth density he prefers rather than that to which he may be forced. There must be some difference of temperature between the two ends of the rotor, but the volume of air can be made sufficient to keep the hotter end within the desired limit. By suitably disposing the stator ducts the temperature throughout can be kept substantially uniform. In addition, when necessary, axial ducts may be arranged in the stator and the discharge from these into the various radial ducts may be separately varied to equalize further the temperature rise. The omission of the radial ducts reduces somewhat the noise of the alternator and also the windage loss.

Fans.—It is quite usual to see, with an otherwise well-designed rotor, fans that are anything but robust in construction. Sheet steel about 1/16 inch thick for the blades and about $\frac{1}{8}$ inch thick or less for the runners is frequently employed, and apparently that the fans will be satisfactory is taken for granted and is not verified by calculation. Several cases have come to the author's notice of such fans collapsing

and striking the stator end windings, with complete breakdown of the alternator. For silent running, the more blades the better, but on the other hand the more blades the greater is the load on the runners. It is unnecessary to postulate that safety must come first, and the permissible number of blades must be determined by the maximum thickness that it is desirable to employ for the runners. By running alternators with and without the fans the author has determined the effect they have on the noise. The difference, though appreciable, is not great. The blades should be given such a thickness that collapse is impossible. For the smaller sizes oil-hardened boiler plate is satisfactory for the blades and runners, but for the larger sizes oil-treated nickel-chrome steel plates should be used.

The loss due to the fans in large high-speed machines is of the order of 20 per cent of the total windage. It is important that the efficiency should be kept as high as possible, since the loss not only affects the alternator efficiency but also adds to the heating. The entering angle of the blades should be the same as the direction of the flow of air into the fan, so that there is no shock. The leaving angle affects the pressure and the direction of the air more than the efficiency. It is usual to make the blade quite straight, but the pressure is increased if the blade is curved in the direction of rotation. The blades and runners should be given a good smooth finish and be coated with a thin hard varnish. With such fans, on account of the high peripheral speed as compared with the air velocity through the fan, the direction of the air leaving the fan is almost tangential. The air, therefore, does not flow axially from the fan to the gap, but is carried round with a high velocity. This action causes some churning and loss, but on the other hand the stator end connections are well cooled. Probably the resistance to entering the air-gap is reduced by the motion, since the air in the gap is being carried round violently by the rotor, but if there are stator axial ducts the flow into them may be less easy.

The author has tried the effect of providing a row of standing blades over the fans to make the air flow purely radially into the end chamber. The air pressure was increased about 15 per cent; the volume of air flowing through the machine was increased correspondingly, and it was therefore decided that there was no gain or detriment in preventing the circular movement of the air in the end chambers.

Noise.—With very high peripheral speeds more noise must be expected than with the lower speeds of a few years ago. A good deal of the noise from an alternator is transmitted through the air leaving it, and the station can be made much quieter if the discharge air is led away through a flue. With a new station there is little difficulty in accommodating the discharge duct in the foundation, and for large high-speed sets it is very desirable to adopt this arrangement.

Balance.

Freedom from vibration is an essential mechanical requirement apart from being desirable for more obvious reasons. With marked vibration, wear of rubbing parts may take place at an extraordinary rate and the soundest construction be weakened in the course of time. A press fit that would be perfectly solid in normal circumstances may become free in the presence of vibration, and relative movement of the parts may take place. Movement of the end windings is more probable, and the insulation under great pressure is very likely to suffer wear. Every component part should be so designed that change of balance is safeguarded against. It is desirable that the degree of balancing should not be left to the judgment of the erecting engineer, but should be put on a positive basis by using a vibration indicator. The grooves for the balance weights should be provided in the disc supporting the bell cylinder; the practice of attaching balance weights to the outer fan runners is most unsound. Much time is saved in balancing, and the final result is often better, if the rotor is balanced statically before running. Although the correct division of the balance weights between the two ends of the rotor cannot be determined statically, the total weight required is determined and adjustment of it only is required when making the running balance. The sensitiveness of the knife edges is much increased by resting the shaft on ball or roller races.

Overspeed Test.

The stresses and pressures for a given rotor increase with the square of the speed. The increase of stress and pressure factors at overspeeds are shown in Fig. 22 based on unity at the normal speed. For proving mechanical soundness the overspeed test fails because it is fatigue failure that is most to be feared, and an increase of speed does not prove capacity to withstand fatigue. The overspeed does directly test the soundness of the rotor teeth and of the end bells, but even its value in this way is limited, because in the event of there being a flaw, due to the ductile quality of the steel, it is more probable that failure will result after prolonged running than at the moment. A great disadvantage is that the overspeed imposes on the insulation an undue stress that is harmful The turbine emergency governor should be set to operate at 10 per cent overspeed, and since some allowance to make sure of the governor operating is necessary it is desirable that the set should be capable of standing an overspeed of 20 per cent. At this overspeed the pressure and the centrifugal force are 44 per cent greater than at the normal speed. The author holds the view that all parts of the rotor should be designed as if it were to run at 20 per cent overspeed continuously. At the normal speed the stresses and pressures are 30·5 per cent less, so that the factors of safety in the teeth and end bells are then very satisfactory.

In summary, high overspeeds (1) do not test the most important requirement—capacity to withstand fatigue, (2) do not necessarily detect the presence of incipient flaws in the highly-stressed parts, and (3) do undoubtedly tend to damage the insulation. An overspeed of 20 per cent is essential, but anything higher is undesirable.

In conclusion, the author begs to express his obligation to Mr. Douglas Vickers and Mr. W. Clark, directors of Messrs. Vickers, Ltd., for permission to read this paper. Also, he takes the opportunity of acknowledging his indebtedness to his colleague, Mr. J. P. Nicholson, who conducted the various mechanical tests referred to in the paper.

APPENDIX.

Specification of Solid Forged Rotor.

Rotor forging.—The rotor forging is to be of high-grade carbon steel annealed after forging and oil treated after rough turning. The forging is to be preferably in a single piece, but if too large for a single forging a hollow cylinder is to be forged on a mandril and is to be shrunk on to a through shaft. The steel is to be made and the forging to be done by an approved maker. Test-pieces are to be cut from (*a*) the end of the shaft, (*b*) the periphery of the rotor in a tangential direction, and (*c*) the end of the core in a radial direction. A tensile test and a bend test are to be made in each case. Test certificates are to be furnished by an approved testing house, giving the yield point, the ultimate strength, the elongation and the contraction of area; or tests are to be made in the presence of the engineer's representative at his option. The stresses are to be calculated at the speed of 20 per cent above normal, and are not to exceed 50 per cent of the yield point of the material. The maximum combined torsional and bending stress in the neck of the journal is not to exceed $7\frac{1}{2}$ per cent of the yield point of the material. Change of section throughout the rotor is to be made gradual and ample radii are to be provided. The rotor is to be given a smooth finish, and in addition the shaft portion is to be finished to a good polish. All keyways are to be carefully cut and radii are to be formed at the ends and at the bottom.

End bells.—The end bells are to be made of high-grade nickel-chrome steel annealed after forging and oil treated after rough turning. The steel is to be made by an approved maker. A test-piece is to be cut from the bell in a tangential direction, and a tensile and bend test are to be made. Test certificates are to be furnished by an approved testing house, or the tests are to be made in the presence of the engineer's representative at his option. In addition, a test-piece is to be notched and broken by impact, and the fracture is to be examined by the steel-maker and he is to certify that the steel is in satisfactory condition. The stress is to be calculated at 20 per cent above normal speed and is not to exceed 50 per cent of the yield point of the material. The maximum and not the average stress is to be taken—i.e. the stress should be calculated on the inner periphery and at the point of maximum coil loading. The end bell is to be given a fine finish inside and out. If in a single piece, the end bell is to be made a good press fit on the shaft and is to be positively driven and is to be retained in position effectively against axial movement. If the cylinder is separate from the supporting disc, it is to be made a good press fit on the rotor core and on the disc. Both disc and cylinder are to be positively driven, and both are to be retained in position effectively against axial movement. With either construction means are to be provided for readily withdrawing the bells to give complete access to the end windings for examination or for repair.

Rotor windings.—The slot insulation is to be of micanite reinforced with suitable non-hygroscopic material, and the total insulation thickness is not to be less than 0·06 inch. The insulation between turns is to be pure hard mica not less than 0·01 inch thick. If radial ducts are used a sheet-steel slot lining to support the insulation must be used. If ventilating ducts are cut at the bottom or sides of the slot, sheet-steel support for the insulation must be provided. The end windings are to be insulated from the end bells by micanite not less than 0·05 inch thick reinforced by suitable non-hygroscopic material. Where the end-coil connections are close together suitable insulation is to be provided between to prevent contact. The end windings are to be effectively wedged to prevent movement. The coils are to be firmly pressed into the slots with a pressure at least equal to the maximum pressure they exert at 20 per cent overspeed. The rotor coils are preferably to be few in number and relatively wide so that the end windings have a maximum of stability.

Slip-rings.—The slip-rings are to be machined from carbon steel forgings containing not less than 0·4 per cent and not more than 0·6 per cent carbon. They are to be insulated with pure hard mica, and are to be shrunk directly on to the shaft or on to a forged steel sleeve shrunk or pressed on to the shaft. The rings are to be heated electrically for shrinking, and not by fire or gas, so that there is no chance of scale being formed that might impair the fit. The relative sizes of the end bells and of the slip-rings should preferably be such that the bells can be completely removed and the windings fully exposed for examination or repair without disturbing the rings.

Slip-ring connections.—The connections from the windings to the slip-rings are to be of ample size and are to be built up of copper laminations not more than 0·01 inch thick. The connectors are to be heavily insulated throughout with moulded or flexible micanite and are to be securely held against the action of centrifugal force throughout their length. Preferably the connectors are to be so disposed that the end bells can be removed without having to disturb them.

Slot wedges.—The slot wedges are to be of steel or gunmetal, and the maximum shear stress and bending stress is not to exceed 35 per cent of the yield point of the material.

Fans.—The fan blades are to be of substantial thickness so that bending and collapse is impossible. Oil-hardened boiler plate or oil-treated nickel-chrome steel plate is to be used for the fan blades and for the runners. The maximum bending stress in the blades, the shear stress in the blade fixing, and the maximum hoop stress in the runners must not exceed 40 per cent

of the yield point of the material calculated at the overspeed of 20 per cent above normal.

SCHEDULE OF PARTICULARS TO BE FURNISHED BY THE MANUFACTURER.

Rotor steel made by :
Rotor forged by :
Tensile properties of rotor steel :—
(*a*) From end of shaft. Yield point :
Ultimate strength :
Elongation :
Reduction of area :
Bending test :
(*b*) Tangential test from rotor periphery.
Yield point :
Ultimate strength :
Elongation :
Reduction of area :
Bending test :
(*c*) Radial test from rotor core.
Yield point :
Ultimate strength :
Elongation :
Reduction of area :
Bending test :
Maximum stress in the rotor teeth :
Maximum combined torsional and bending stress in journal :
Maker of steel for end bells :
End bells forged by :
Tensile properties of end bell material :—
Tangential test. Yield point :
Ultimate strength :
Elongation :
Reduction of area :
Bending test :
Maximum stress in end bell :
Material used for slot wedges :
Tensile properties of slot wedge material :—
Yield point :
Ultimate strength :
Elongation :
Maximum shear stress in slot wedge :
Maximum bending stress in slot wedge :
Material of fan runners :
Tensile properties of material :—
Yield point :
Ultimate strength :
Elongation :
Reduction of area :
Bending test :
Material of fan blades :
Tensile properties of material :—
Yield point :
Ultimate strength :
Elongation :
Reduction of area :
Bending test :
Maximum stress in fan runners :
Maximum shear stress in the blade fixing :
Maximum bending stress in the blade :
First critical speed :

DISCUSSION BEFORE THE INSTITUTION, 21 MARCH, 1918.

Mr. A. B. Field : The development of the alternating-current turbo-generator during the last few years has been rapid, and the requirements of the immediate future give promise of demanding an equally rapid further advance in methods of construction for very large units. The problem was originally, let us say 13 years ago, largely an electrical one, but now that individual units reach 50,000 kw. output, and with a very possible demand nearer to 100,000 kw. per set in the early future, the mechanical aspects largely predominate. We ought then to be far more ready to accept electrical imperfections (excluding insulation weakness) than to tolerate poor mechanical features. It is therefore gratifying to find the author dealing with the subject so largely from the mechanical point of view. Reading the paper through, one cannot but feel that the author has sub-consciously had in mind chiefly 3,000-r.p.m. machines, although references have been made to other speeds ; and this would largely explain some apparent incongruities and irrelevancies. The immediate outlook for 3,000-r.p.m. machines may reach some 10,000 kw. or so per unit ; but for the coming really large units, the lower speeds of 1,500, 1,000, and 750 r.p.m. will be necessary. For 3,000 r.p.m. I am entirely in accord with the author as to the preferable, one might almost say necessary, use of a solid forging. Indeed, I want to endorse so much in this paper that I must in the time available confine myself entirely to points of contention. Many thoroughly satisfactory machines for speeds between 1,000 and 1,800 r.p.m. have been built in the past, using laminations assembled on a shaft, but nowadays machines of such ratings—which are essentially small machines—would, except in special cases, be built for 3,000 or 3,600 r.p.m., and our interest in laminated rotors becomes largely historical. Coming then to the larger and lower-speed machines, our choice of construction lies between the use of a single forging ; a multiple-part forging, the components being still large ; forged discs ; and rolled plates. In each of the last three cases we might have a through shaft, or we might not. The construction which is most suitable will vary with the rating. It will also depend upon steel-market conditions and upon facilities in the country in question. With the exceptional metallurgical facilities at the beck and call of the author, a construction will frequently become desirable which would be questionable elsewhere. I need not lay further stress upon the point. Those who have been dependent upon buying large forgings in the market, merely upon a purchasing specification and inspection basis, will appreciate the point at once. The author criticizes

at some length on page 475 a construction which I described a couple of years ago.* As I was responsible for the first series of these machines, I should like to answer these criticisms. I refer to the construction in which the rotor is built up of rolled plates slightly under 2 inches thick, without any through shaft, a construction suggested by Behrend and which I believe to have been absolutely sound under the American conditions where it was adopted. Further, I believe it has still to find its usefulness in this country, not perhaps for the units of 20,000-kw. rating where it was first used, and which could be built no doubt by the author with single forgings, but for the larger sizes where new conditions are going to arise—conditions perhaps not yet quite realized by any of us. With this construction the plates are rabbeted into one another and into forged, flanged shaft ends, and the whole structure is held together by four or six bolts. I call them bolts, but even taken by themselves their moment of inertia would compare not unfavourably with that of a through shaft advocated by the author. They were 4 inches or so in diameter, on a pitch circle of about 41 inches diameter; and thus by themselves, and entirely ignoring the very much larger compressive areas around them, they provided a moment of inertia for resisting bending effects equal to that of a 21-inch diameter central shaft. And this refers to the smaller rotors (1,800 r.p.m.). If the bolts were quite loose, the stress in one of them at the bottom of the rotor, just to prevent the rotor plates from opening, would be 4,000 lb. per square inch, but the initial stress applied to these chrome-nickel steel bolts was 10 times this amount. Even this statement is quite unfavourably misleading, because the variation of bolt stress in an entirely loose structure is radically different from that in a solidly tightened-up one, as will be evident upon a close examination of the problem. It may be conservatively stated that the variation of stress in these bolts upon rotation of the rotor is certainly under $\pm$ 700 lb. per square inch, i.e. it is under $\pm$ 2 per cent. In view of this information it will be seen how misleading is the author's quite incorrect statement on page 475 that "at the underside of the rotor the plates are out of contact." His next two lines are correct, literally, but also misleading. At each revolution a variable stress *is* superposed as he states, but its value is this trifling 1 to 2 per cent. The author proceeds, that in a 1,500-r.p.m. machine this cycle of stress is repeated over 2 million times per day. Yes! and some of these machines run at 1,900 r.p.m., giving more nearly 3 million cycles per day; but curiously enough the rotors have stood this terrible treatment not for one day only, but for nearly five years already. The author refers to some form of plate-built machine which he inspected and in which he found trouble after 2½ years' operation, but fortunately he gives us the rating of the machine, which is 6,000 kw. at 1,500 r.p.m. It is impossible to discuss the case without some information upon it, but I do know that no ratings anything like as small as this were built along the particular lines to which I have been referring. Returning to the question of fatigue in the bolts, I believe my statements have already adequately dealt with this; but if we turn to the later construction even the hypothetical argument fails. The bolt shown in Fig. A, although parallel and a press-fit in its hole, has a cross-section along 85 per cent of its length somewhat less than that at the root of the threads; there is adequate provision for its centrifugal force to be accepted by the rotor body; while in a circumferential direction we have the full dowelling action as before. The bolt is pressed in, and keys are provided to take the torsion at the end from which the tightening is done. A little convenience in the shop assembly is gained by the special type of keys shown, which cut their own shallow keyway, a few inches long, in the rotor material as the bolts are hydraulically pressed home. This avoids any necessity of twisting the bolts, as they are being pressed in,

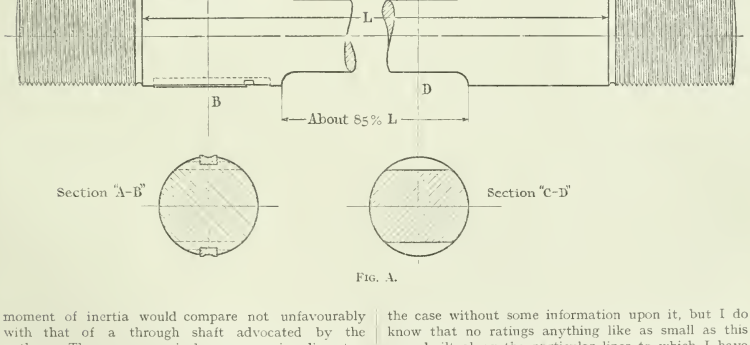


FIG. A.

* *Journal I.E.E.*, 1916, vol. 54, p. 65.

to line up the keys with previously cut keyways. The author refers to the critical speed, and mentions a point I drew attention to previously as a theoretical deduction, namely, that with such a construction there is no true critical speed. I may repeat that this was a purely theoretical deduction of mine, as the machines referred to have not been run up to their critical speed, which is above the running speed. I must protest against this statement at the bottom of page 475. It can be indisputably demonstrated that the deflection of such a built-up rotor must be the same as that of a solid forging with the same slotting and venting, as long as the compression does not vanish on the lower side, and the stresses remain within the elastic limits.* If my statements and argument above be accepted, then this paragraph of the author's must be abandoned as incorrect. In general, this plate construction is not a cheap one. With the relative steel prices in force five years ago, it was costing practically the same as for the solid forging method. It does, however, give a rotor in which the quality of every cubic inch of steel is known, and in which the only initial stresses are intentional ones. The advantage of eliminating all the unknown internal shrinkage stresses of the rotor body is obvious. At the bottom of page 478 the author hesitates to recommend a single forging for the largest 1,800-r.p.m. machines likely to be required. He advocates using a drum, forged on a mandril, and shrunk on a through shaft. Let us examine this recommendation cursorily. On account of the end rings we cannot at present go much beyond 52 inches or 53 inches diameter. We need something like 6 inches slot depth for the coils and the heavy wedges required. We need an air slot below that, and 4 inches is little enough for a really large machine and long rotor. So our slotting will run down to a 32-inch diameter or so. Even a 20-inch shaft becomes out of the question unless we accept stresses of the order of 45,000 lb. per square inch. We might thread the rotor drum on a 15-inch diameter spindle and call this a shaft, but we still should have a stress of about 35,000 lb. per square inch. A diameter of 15 inches might perhaps just allow the shaft to be tapered down to a reasonable journal size. While the above slot depths roughly accord with recent practice, I agree that by putting up with certain disadvantages, for instance, very narrow rotor slots and so on, the figures may be modified. I question, however, whether the author had really closely studied the problem of the largest 1,800-r.p.m. machines when he wrote his recommendations. It still remains possible to use a hollow forged drum with a comparatively small bore and two separate shaft ends. In this connection I have generally been in favour of a central bore, anyhow, in the case of large-diameter single forgings, arguing that a stress of 28,000 lb. per square inch at the surface of a *smooth* bore is preferable to half this figure in an almost glass-brittle central core in which a possible flaw may produce an effect kindred to that in a jagged-edged hole. The bore also considerably aids heat treatment and allows a certain degree of inspection. In the matter of end rings, I am entirely in accord with the author as to the desirability of using chrome-nickel steel except for very small machines, and then heat-treated carbon steel generally. Occasionally some manganese bronze becomes necessary, but, as the author points out, this has a very doubtful elastic limit although a good yield point. In the case of a composite ring, namely chrome-nickel steel with a bronze tip, I must admit being one of those condemned by the author for checking the bronze into the steel, that is, the reverse of the way shown in Fig. 20. I am afraid that I remain quite recalcitrant. Chrome-nickel steel, when properly handled, is certainly reliable, but one cannot say the same of bronze. Its lack of really good elastic properties makes one suspect its ultimate endurance, and such a bronze tip should preferably be checked into the rotor body, leaving a carefully determined clearance for diametrical expansion, and should be checked into the steel ring on the other side. The rotor tooth should be strengthened for this additional load by using a large-radius fillet at the ends of the cylindrical parts of the rotor body. But even on the author's own showing, is he correct about Fig. 20? He limits the bronze stress on page 484 to 45 per cent of the yield point (surely high enough), that is, 10 tons per square inch. He places his chrome-nickel steel figure at 50 per cent of 40 tons, i.e. 20 tons per square inch. He therefore limits his safe bronze stress to half the steel figure; but his value of Young's modulus is 68 per cent of the steel value, hence the steel tends to stretch more than the bronze. With the design of Fig. 20 the bronze is forcibly stretched by the steel, and receives a stress which is 68 per cent of that in the steel instead of the allowable 50 per cent. I have always used a lower value of the bronze modulus, but even so I consider the correct construction remains as I have described it. The author advocates registering these end rings on the projecting rotor slot wedges to avoid magnetic leakage and to gain other advantages. This, again, is a temptation to be resisted; the electrical disadvantages should be accepted rather than the mechanical ones. The problem of stress distribution in these end rings is a very complicated one. The actual loading not only varies axially, but circumferentially, and bending stresses of the ring material arise in both the planes of the circle and those through the axis. In some cases the distortion from the circular shape more than eliminates the radial expansion on certain radii unless the ring can come down solidly upon a support and call into action very substantial supporting forces. Unless due provision is made for this, the additional ring stress due to bending in the plane of the circle becomes very serious indeed. These secondary stresses are usually ignored. The author stipulates that in calculating the end-bell stresses the maximum is to be taken (page 489), but this seems to refer mainly to the inside versus the outside ring stress, and to the maximum value in the axial distribution of coil loading. In fact the actual stresses, including secondary effects, as indicated above, can only be approximated to by somewhat laborious methods, and their estimation by different calculators would not be likely to check closely. In the matter of test bars, the radial bar of Fig. 6 should be taken by a trepanning

* This point is further dealt with below in my "Communicated" remarks.

tool at the centre of the length of the rotor, and not at position "C" where the oil-hardening has had the greatest opportunity of being effective. Again, with the chrome-nickel steel rings at least two, or perhaps three, test bars should be taken from each ring, especi-

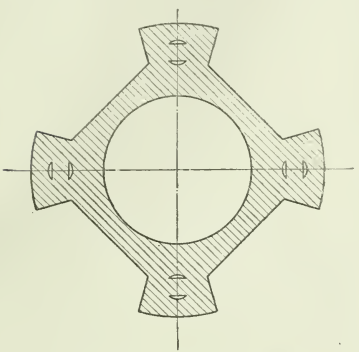


FIG. B.—Original cross-section of beam.

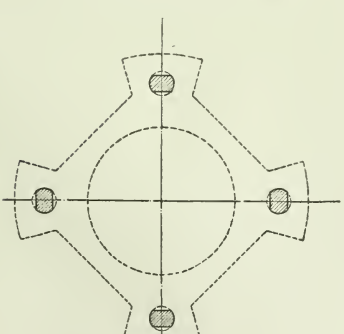


FIG. C.

Regions (1) shown by full lines and cross-hatching.
Regions (2) shown by dotted lines.

ally if these are of a size necessitating forging on a mandril rather than in a tire mill. The appendix (page 489) needs some careful revision before being accepted as a good purchasing specification. Such a specification should undoubtedly aim at ensuring an absolutely sound design and construction while giving the greatest possible freedom to manufacturers in matters of details of design.

(*Communicated*): It seems advisable to give somewhat more completely * the correct statement as to the theoretical stiffness of a plate-built rotor, as there is evidently still some misconception upon the subject. Let us consider a beam of varying section, and let this be subject to bending actions producing moments M, M being a function of x, the distance from the centre. The beam we are considering is a solid single-piece one. At any one value of x, let us mark out on the cross-section of the beam (Fig. B) certain regions symmetrically about the principal axes of section, aggregating A_1 square inches at a radius of gyration of k, so that the moment of inertia of these specialized regions aggregates $I_1 = A_1 k_1^2$. Fig. C shows these regions in full lines. Let the suffix "0" refer to the original section, "1" to the specialized regions, and "2" to the remaining regions. The system of forces comprising T_1 lb. per square inch tension uniformly distributed on the "1" regions, together with $T_1 A_1/(A_0 - A_1)$ uniform compressive stress on the "2" regions, is itself in equilibrium and produces no bending moment. Hence if this system be superposed upon the system of interface forces which constitute the reaction to the bending moment M at the section in question, and if as a result all stresses remain within the elastic limits, then neither the equilibrium nor the curvature of the beam at this section will be affected by the added system. If we proceed further and eliminate the longitudinal shear stress around the contour of the regions "1," we may imagine these regions to be actually separated around their contours without affecting the case, and we then have the case of a solid rotor of section "2" with longitudinal tension bolts "1," giving the same deflection everywhere as the original rotor "0." Or, without any proviso as to the longitudinal shear stress, the deflection will at any rate be less than that of the solid beam of section "2." If we make the initial tensile and compressive stresses such that under the bending actions we never get any tension anywhere in the region "2," and if we provide suitably for transverse shear (e.g. by rabbeting), then we may without affecting the case have any number of transverse partition planes in the material of region "2" without affecting the equilibrium or curvature at any section, and hence without affecting the deflection. But we now have the complete case of the plate-built rotor, and we see that its stiffness depends, not upon I_1, but upon I_0.† It is fairly evident that, practically, the reactions at the ends of the bolts sufficiently take care of the effects of longitudinal shear stress around the contour of regions "1." If we add the refinement of making $A_1 M/I_0$ approximately constant along the length, we eliminate the minute remaining shearing action at this contour. Having determined the deflec-

* See also *Electrician*, 1918, vol. 80, p. 817.

† It should be noted that I_0 is dependent almost solely upon the unslotted regions of the cross-section of the rotor. In the case of the single forging—unless ventilated axially only—radial vent grooves are parted down in the polar regions as well as in the slotted ones, and consequently only that area of cross-section which is below the bottom of these vent grooves is available in the determination of I_0. In the case of the plate rotor, the radial vents are obtained without cutting into the polar regions (see *Journal I.E.E.*, 1916, vol. 54, p. 69). Hence the deflection of a plate rotor of given dimensions and coil slotting may even be less than that of the corresponding rotor constructed from a solid forging.

tion of the built-up rotor by reference to that of a solid one, the stress variation in the bolts consequent upon rotation of the structure immediately follows. Such stress variations as occur must result in corresponding variations in the elongation. The changes of elongation and of stress will be related by $l/L=f/E$, where l is the overall change of bolt length consequent upon the stress change, and f is the average, taken over the bolt length L, of the change of stress. E represents Young's modulus for the material of the bolt. Since the deflection of the structure is the same as that of the specified solid one, the change l will be the same as that of the fibres in the corresponding position in the solid case. Hence f is the same as the average (over the rotor length) of the stress change at the corresponding spot on the cross-section of the solid rotor. It is independent of the bolt cross-section and of the initial bolt stress so long as this is sufficient to comply with our assumptions of a "tight rotor," or one in which the compressive stress does not vanish in any part of the region "2" upon the application of the bending moments in question. It is hardly necessary to add that if this condition be not met, the change of bolt stress upon rotation of the structure will be greater than indicated here, and may be many times as great. This fact is in complete contradiction to the statement made and reiterated by the author in this connection. With regard to the general question of the relative merits of a single versus a many-part rotor structure, when large sizes are involved, the author very properly lays stress repeatedly in his paper upon the essential importance—when a single forging is used—of exercising the highest technical skill and experience in the production of the forging, from the pouring of the ingot down to the heat treatment after rough machining. He rightly emphasizes the fact that defects which may be present in the forging cannot necessarily be detected by an over-speed test or other acceptance tests at the factory or on the site: the results of such defects may only appear after continued operation. In the same way with the plate-built rotor, defects might remain undetected by the acceptance tests. Moreover, while the same degree of expert technical skill is not demanded in this latter case in the production of the material involved, it is essential in order to obtain the desired results that thoroughly first-class workmanship shall have been maintained throughout. The question of the relative probability of faults developing appears to centre largely upon the relative facility with which the processes involved can be effectively inspected and checked during the production of the material and finished article in the two cases. I believe that the processes involved in the case of the plate-built rotor are more readily amenable to rigorous inspection, since they involve methods such as micrometer measurements, gauging, etc., which have been developed to a fine degree of perfection in even the most ordinary engineering shops.

Mr. F. H. Clough: A great many of us have gained to-night quite a lot of new information on steel, which will be very useful to us in designing machines. I disagree, however, with many of the author's statements. He practically condemns all constructions except the solid rotor, and it seems to me he passes over its obvious disadvantages rather lightly. I have been responsible for a large number of machines aggregating about a million kilowatts and I have used the laminated rotor throughout, and in no case have we had failures from the causes which the author mentions, such as failure of the punchings due to over-rolling or similar causes. We certainly use cold rolled punchings, not fully cold rolled but hardened by the cold rolling, and I think we are justified. The elongation is 10 to 15 per cent. I think we find justification for that even in the paper. The author touches lightly on the use of binding wire for rotors and says the advantage of this is that one can use steel at a tensile strength of approximately 100 tons per square inch, which so far as I know is obtained in identically the same way that the higher stresses are obtained with the cold rolled punching. The stress on the rotors is applied in a very gradual way; it comes on very gradually as the speed increases and comes off again as the speed decreases. It is an ideal stress in many ways, and I think we are therefore justified in using a material which does not necessarily have a very high elongation. Such a high elongation is only necessary where the stresses are indefinite and are divided up amongst various members of the structure depending upon the deflection of the other members. In the case we are considering, however, each punching takes care of its own stress independently of the others, or largely so; the stress is gradually applied, and therefore I think that material of about 40 or 50 tons ultimate strength and 30 to 35 tons elastic limit with 10 per cent elongation is very suitable for the purpose. In my experience it has been satisfactory in every way. It is rather difficult to judge the whole case if we consider only the mechanical side, and the reason for using punchings is not wholly mechanical. It does give one a very much better chance of ventilating the rotor than the solid forging does. I have the advantage of being able to compare my own tests with those on machines having solid rotors, and the temperature rise is very much less with laminated rotors than with solid, of the order perhaps of 60 per cent. It will be seen that this allows the rating of the machine to be very considerably increased. In fact, the output is limited not so much by the rotor but probably by the difficulty of using sufficiently large conductors or a sufficient number of conductors on the stator to prevent overheating. The use of a solid rotor is very often put forward, not so much from the point of view of strength, as that it avoids a critical speed. With the largest machines which we now have to build for a speed of 3,000 r.p.m. it is no longer possible to avoid the critical speed; therefore it has to be passed through, and it does not matter very much at what speed this is done, so long as the deflection is reasonable and the shaft is otherwise adequate to the duties. All the machines for which I have been responsible have passed through their critical speeds and have given no trouble. The biggest machine is about 7,000 to 8,000 kilovolt-amperes, but bigger ones are in contemplation.

Dr. S. P. Smith: It is to be hoped that this paper

will give confidence to those consulting and operating engineers who have the idea that machines cannot be designed or built in this country which have not been previously designed or built elsewhere; and if consulting engineers would insert a clause in their specifications that machines must be designed as well as built in this country, instead of stating—as some do—that no firm need tender unless it can show machines as big or bigger running satisfactorily in this country it would give English designers much encouragement and enable them to show the world that they can tackle these problems at least as well as designers abroad. In the discussion on the laminated rotor versus the solid rotor, there is one peculiarity about the laminated rotor which the author does not mention. In rolling wide plates there is sometimes a tendency for the plates to be a little thicker in the middle than at the sides, due to the rollers moving a little apart in the centre; consequently care should be taken to stagger such plates, so that this want of uniformity will not produce a rotor of varying axial length. I remember a rotor which had bolts through the teeth, instead of plates at the ends, to hold the laminations firmly together, where the core length measured at the periphery was found to be an inch shorter than near the shaft, thus illustrating how a rotor built up of thin sheets may vary in length. On page 476 the author refers to an Institution paper of mine read in 1911 where the best ratio of the number of wound slots to the number of pitches per pole was discussed. As confirming his statement I might mention a case recently brought to my notice, where there were 15 slot-pitches per pole. If we had 6 coils, that is 12 slots, the ratio of the wound part to the whole pitch would be four-fifths. If we had 5 coils in 10 slots, the ratio would be two-thirds, and we saved a coil. The interesting point was that for the same excitation loss we got more flux with the smaller number of coils. I am glad the author has drawn attention to this, because that paper was read about seven years ago, and the point has been overlooked by some designers in quite recent years. It is safe to say that in general a ratio of two-thirds is better than a ratio of three-fourths. The true way to get the maximum output is to use variable spacing of the slots—even with respect to the pole-centres—and we are obliged to do this for very large outputs and when the conditions are special. In other words we can further increase the rotor output by proportioning the slot-pitches in the proper manner. The author refers on page 483 to the loss on short-circuit. It is an undoubted fact that something peculiar happens on short-circuit which does not happen on load. There is usually much greater heating in the stator conductors on short-circuit than with the same current on load. I think flux from the stator enters the end bell more easily on short-circuit than when the machine is running normally, because in the former case the rotor and stator ampere-turns are about equal; whilst when working at full load, the rotor ampere-turns are much stronger and practically saturate the bell; consequently the bell offers considerable reluctance to the stator magnetomotive force on load. There is no doubt that the losses which occur on short-circuit are very different, both in distribution and in magnitude, from those on actual full load. I have spent a good deal of time in investigating the matter, but up to the present moment I have not been able to trace any direct relation between the losses which occur on short-circuit and those on actual load. It has been suggested as a means of testing turbo-alternators that all measurable losses, including the short-circuit loss, be taken into account, and I think it has been authoritatively put forward in America that the efficiency based on these losses should be accepted as the conventional efficiency. Though it may be convenient to use the short-circuit loss in calculating a certain conventional efficiency, yet I am very much in doubt whether it has any real meaning. Probably the best way of measuring the efficiency is to find the loss on load from the temperature rise of the cooling air. I am glad the author has drawn attention to the fact that one must be careful in using short-circuit losses, as they are probably meaningless in many instances. In addition, he has shown that it is probably very unsafe to run large machines on short-circuit for any length of time, as it might seriously damage the insulation.

Mr. A. R. Everest: The author states that the object of the paper is to prepare a specification which can be used for the guidance of the customer's technical adviser, presumably in cases where he has not the necessary familiarity with the subject to express his own preferences. Personally, I think that if the consulting engineer himself cannot say what he prefers to have, he should trust the designers of firms having proved reputation. I find the paper rather contradictory. We have the statement: "With the advent of peripheral speeds of over $4\frac{1}{2}$ miles per minute the unsound construction of earlier times had disappeared, and the modern turbo-alternator rotor is not surpassed as a high-class engineering production." That I take it is an admission that the engineers responsible for these machines are making their designs satisfactorily, but at the bottom of the page there is another paragraph which reads: "The conditions to be faced are most severe, and the author doubts if they are sufficiently well realized by either user or maker." That is in contradiction to the previous statement. I feel very emphatically that it is one thing to have a standard British specification for a material; but such things as standard specifications for ships or machines are only adopted here as war expedients, and I do not think we want to consider a standard specification for a turbo-alternator. It means taking one man's design to the exclusion of everybody else's. With regard to the preference expressed in the paper for certain types of design, of course every designer has his own preferences, but I would suggest that the author is too positive in condemning some well-known types of design, and that a selection of one to the exclusion of the others is not justified, particularly as it is proposed for adoption as a kind of national standard. With reference to the preference expressed for the solid rotor and the condemnation of the laminated rotor, the principal objection pointed out against the latter is that if we build it of punchings we must have central

holes to string them on to the shaft, and the author points out that a solid disc with no hole at all is twice as strong as one with even a very small hole. A little further on we find it stated in connection with solid steel forgings that when we get up to outputs of 8,000 to 10,000 k.v.a. the solid forgings become so unreliable that it is necessary to bore out the centre and put in a separate shaft. The argument is entirely gone. As Mr. Clough has already pointed out, the laminated rotor has been in use for several years and at present something like a million kilowatts of such plant has been running for from one year up to 10 years and there is nothing in the history of their performance which justifies their condemnation in preference to any other construction of which I know. Further, experience indicates that with the laminated rotor we get better ventilation than those who design the solid rotors succeed in obtaining. Designers agree that the dimensions of the large machines which are wanted in future are controlled very largely by the temperatures at which we can run the rotor windings, and therefore controlled by the temperature limits imposed on the insulating materials we can use. Everything comes back to the temperature which is permissible on the rotor, and if a certain construction enables us to get better ventilation so that we can get a bigger output for a given temperature limit, surely this is an argument in favour of that construction.

Mr. H. W. Taylor: The author has gone with considerable detail into the defects likely to be found in steels as used in the various types of machines, and I feel that if some of the previous speakers had not given evidence that some of the types of machines under review had proved satisfactory in operation over a number of years, the paper might have had a disconcerting effect upon operating engineers. One of the obvious criticisms of the laminated rotor is that when running at full speed the laminations will expand and so throw the rotor out of balance. It is found, however, that with reasonable precautions, this effect does not take place, and the probable reason is that, as hinted by a previous speaker in connection with end rings, the stresses although relatively simple are complex enough as to cause unequal radial expansion, so that at full speed a lamination takes the form of an ellipse and grips the shaft at some places and leaves it at others. The author has suggested a possible limit in the size to which machines could be built with laminated rotors. I do not suggest that the largest machine ever to be made can be of this construction, because as we design machines for larger and larger outputs we look at the whole problem broadly and it may be that there is a limit; but in order to show that the limit is not yet reached I would mention two points:—(1) That the stress being more severe in the end bells, the stress in the laminations is not the limiting feature in the mechanical design. (2) The specific dimensions given for certain machines in the paper are rather larger than are necessary for a design with laminated rotor, and therefore a 5,000-kw. rotor running at 3,000 r.p.m. is perhaps more feasible than the author thinks. With reference to the keying of the laminations in Fig. 1, I would suggest that the key might be put at the polar region where there need be no slots. The stresses in the lamination are thereby reduced. Speaking of magnetic features, the author seems to suggest that saturation should be concentrated in the rotor teeth, and he has shown a magnetization curve up to 20,000 lines per square centimetre (130,000 lines per square inch). I think it very inadvisable to arrange for the saturation to be concentrated in one region, because one cannot be certain that in different parcels of high-tension steel the magnetizations at these densities will agree to within 20 or even 30 per cent. It is therefore better to distribute the saturation, as it may be necessary to reject materials on magnetic properties, although they are otherwise quite satisfactory. With regard to temperature-rises, especially on the stator core, which occur during short-circuit heat runs, machines are not designed nowadays so close to temperature guarantees as formerly, and the designer is usually content to know that if his machine is within the guarantee with tests based on short-circuit heat runs, it will be well within the guarantee when running on full load when the extra heating due to the circulation of the stator current is much less. At the same time the question of heating on short-circuit heat runs is an interesting study, and one of the principal factors is the pitch of the stator winding. Extra heating, as mentioned in the paper, may also be generated locally at the ends of the stator, but this is probably due to the arrangement of the end connections of the stator winding. Various speakers have referred to the question of ventilation. Wherever axial holes are used, either in the stator or rotor, I think they should be in such a position that they are accessible for cleaning, as soot and dirt may collect in them if the air is not filtered or if the machine is not overhauled at regular intervals. It appears, from experience with the laminated rotors with radial ventilating spaces, that the centrifugal force is sufficient to prevent dust and dirt accumulating in the passages, although this may occur in the stator. It seems to me highly probable that solid rotors which are cooled only by axial ventilation are very likely to become clogged, especially if the individual openings are of small section.

(The author's reply to this discussion will be found on page 509.)

Yorkshire Local Section, 12 March, 1918.

Mr. W. M. Selvey: In some respects I think this paper is the outcome of Professor Field's paper of two years ago. Members then criticized rather adversely the method of holding solid rotor plates together by bolts in order to have the centre of the rotor unpierced by a hole. A little previous to that date we were not making very large machines in England. The Americans were a long way ahead of us in that direction. We were generally departing from salient-pole machines and using these forged rotors with dis-

tributed field windings. I am not quite able to follow Dr. Barclay where he lays undue stress on the subject of rotors built up of thin plates. I have not come across very many of these and in most cases they are only small machines. The advent of the 3,000-r.p.m. machine practically settled the forged type of rotor unless we adopted alloy steel for threaded discs. Although we have very largely got over the trouble with our rotors at the electrical end by making a solid forging, we are still very much in the position of needing alloy steels at the low-pressure end of the turbines where the stress is higher than that to be met in the electrical rotors. The net result has been, as the author has now put forward, that to-day, with the exception of the end bells, our largest rotors are practically a solid forging. The only misgiving we had about these in the first case was voiced by Dr. Barclay at the meeting when Professor Field read his paper, namely, the question of the homogeneity of the steel with regard to its strength in different directions. That point is dealt with in the present paper, which removes any misapprehension we might have had as to the way the forging is strained, having consideration to the way it is worked under the press. With regard to internal flaws, the author gives us to understand that if we go to the right maker—the paper says "approved maker"—we need have no misgiving. I am glad that is so, as although we can find with X-rays an internal flaw in a small casting, I do not know that we can yet take a 15-ton or 20-ton forging and find a flaw by that method. Having arrived at a satisfactory solid forged rotor, we have still two serious questions in large modern rotors. One that has been always a bugbear is the supporting of the end turns. The second is the question of cooling, not only the end turns, but the turns where they pass through the slots. I have been very interested lately in examining a number of designs of 25,000-kw rotors, some of which represent our best English practice and others are adaptations from the considered practice of the General Electric Company of America. There are some fairly striking differences in principle between the various ideas expressed. I should like to touch on an interesting point which the author has not dealt with fully. I think we should pay particular attention to Fig. 23. No feature of a rotor has given more trouble to designers than the cylindrical part of the drum which in Fig. 23 is seen enclosing the end turns. Generally speaking, that has not been made of late in a solid piece as the author shows, though it has had something corresponding to a spider as an end clamping-plate. Almost invariably, except in low-speed rotors, it has been made of a hoop of magnetic steel, and it has been the most stressed part of the whole rotor. It has also been the most difficult to cool. It is relatively inaccessible, and is the place where dirt has most collected. Troubles which have been very puzzling have arisen through heating. There has been heating of the stator core end above this end bell and also of the end bell itself. The only explanation put forward for some time was "unbalanced loads." This was not always borne out; neither have such troubles always appeared with a definitely unbalanced load as were expected. There have certainly been eddy currents which have caused some heating with consequent expansion. And these, together with the loading due to centrifugal force, as the author points out, have stretched the bell until when running it is practically floating. This gives the bell a tendency to settle not quite in place on shutting down; it also gives it a slight tendency to go out of the circular shape. The particular form of end bell in the design suggested by the author is to be made in one piece down to the shaft, so that decentralization cannot occur. In order to ventilate the end turns he is now practically forced to adopt the slots shown under, in order to let air in. This is a return in many respects to some of the earliest 3,000-r.p.m. machines of Messrs. Parsons where we had undoubtedly excellent ventilation and did not have trouble in supporting these end coils. There were several rings made down solid to the shaft with ventilating holes. The coils were, however, threaded through, whereas the modern design has former-wound coils. The ventilation of these coils is a very burning question. Most of us know now that many forms of air cleaners do not clean the air. As a rotor of this kind is very largely dependent on getting the full amount of air passed through it, if these slots show any tendency to get dirty it is not safe to run the machine without dismantling it fairly frequently for cleaning. Hence it will be necessary either to do away with the slots or to construct the rotor so that the slots can be very readily cleaned. I am afraid the author's design does not fulfil either condition. I think that the question of the distribution of the flow of air through the air-gap and the windings and stampings is not considered to be a very difficult problem. There is a large area for flow of air and the heat losses are very well distributed. Generally with modern designs there is no particular tendency to short-circuit the air flow in any one region and so leave hot spots. The cooling of the rotor is, however, a more difficult problem. A number of small radial slots tend to get easily clogged up. If the air is fed entirely from one end, the far end is hotter, the more so as the amount of air which can be got through a long thin slot provides a feeble means of carrying away any considerable quantity of heat; and but for the fact that the rotor coils have considerable heat-dissipating powers by conduction to the metal, and this latter good dissipation from the outer surface, we could not, I think, have made successful large rotors. Certain manufacturers have gone to the length of using water-cooled slots in these places. It has been successful up to a point. I think we still have a certain amount of uneasy feeling that it is not quite the final solution of the problem. It seems too complicated, and steps are being taken to experiment with a large rotor without ventilating slots at all. I would suggest to the author that he might modify his design by putting two fans in parallel at each end and give up the idea of discharging the rotor air separately. I think it is then possible to draw the air from the slots so that adjacent slots carry air moving in opposite directions, one set of slots to one fan and the alternate set to the other, at the same time drilling holes in the end discs which will give the air a straight

path. This would equalize the temperature throughout the rotor. A small detail is that I believe it is quite wrong to try to force a fan by turning its blades forward. This was developed in some of the early French designs and by Davison for the purpose of getting a very large output from small turbine-driven fans. It is not the best method. Some of the fans now fitted on a big rotor approximate to a real fan of a fairly high efficiency in which the air does not necessarily circulate principally in a tangential direction.

Mr. J. Shepherd: Heat treatment for steel forgings of small size is fairly well known, but I should like to ask the author how are large forgings dealt with to render them uniform in structure and free from internal strains. Abroad one hears of machines of 40,000 to 50,000 k.v.a., but one of the factors limiting the capacity of machines appears to be the maximum size to which it is possible to press a rotor forging with certainty of obtaining a sound and reliable interior. In this connection one would like to know the capacity of the machine having the rotor shown on page 479. As the author states, the limiting output of a rotor is determined by the heat loss. With a 50,000-k.v.a. machine the rotor loss is in the neighbourhood of 1,000 kw., depending upon the design; and to dissipate that amount of energy in the form of heat is a serious matter and becomes almost an impossibility with air cooling only. With either a wet or dry filter it is difficult or impossible to clear the cooling air of mechanically suspended dirt; and if the dirt be not removed it will settle in the air passages of the machine and gradually reduce the flow of cooling air. The support and cooling of the end loops of the rotor winding is another serious problem: the alternate expansion and contraction of the copper coils give rise to chafing of the rotor insulation at the ends of the rotor core. At the best the capacity of air for cooling is very limited as compared with a liquid such as water, the respective cooling capacity of a cubic foot of air to a cubic foot of water being 1 to 3,400. Further, there is the difficulty in cleaning the air passages after prolonged use, and the difficulties of correct permanent distribution of the air in different parts of the rotor and stator. In fact the difficulties with air-cooling are so many that with large machines it would appear that air-cooling will require to give place to liquid-cooling, with considerable modification in the general design of the turbo-generator.

Mr. C. N. Hefford: The author has not quite convinced me regarding the safety of making these large rotors in one piece of steel. I can understand that the investigation which he has suggested is exceedingly effective in the case of smaller pieces, but I do not see how we can deduce from the microscopic examination of a test piece the actual state of the steel in the centre of a large rotor of 40 or 50 inches diameter. He states that an alternator with a solid rotor can quite well be designed to withstand short-circuits at the terminals without damage. I find that alternator builders are very chary of agreeing to a short-circuit test, no matter what type of rotor is put forward, and I should like more information on this point. A remark on page 473, regarding the shrinkage of plates or stampings on the shaft, affects over-speed tests. One of the principal alternator builders in the country makes a rotor with a "boiler plate" structure, and I believe is one of the few manufacturers who carry out a high over-speed test in their shops. It makes one consider how far they are wise in doing so. Obviously there must be a very high initial strain on those plates when they are shrunk on the shaft, or the over-speed test would tend to loosen them. On page 474 the author states that "an entirely satisfactory high-tensile plate could be produced using nickel-chrome steel." A rather large alternator is going through my hands just now and there was very great difficulty in producing the rotor for that machine. We tried several types of steel and eventually had to make the rings, which were shrunk on the shaft, of nickel-chrome steel before we could get the mechanical and electrical tests satisfactory. I think the author has made a very important point with regard to lamination and vibration. One can quite well follow his suggestion that we may have a very stiff rotor to start with, built up of laminated plates, especially thin laminated plates, which after a period of running due to vibration may not be anything like as stiff. If we get movement of the plates the coils on the rotor will sooner or later break down. The author's statement that solid forgings are undoubtedly preferable for all sizes of rotors for polyphase work, will of course be modified by his reply to my question as to the difficulty of ascertaining defects in a solid forging. On page 474 he refers to the weakening effect of punching metal sheets. That is not new. Years ago manufacturers stopped punching holes in boiler plates for the same reason. The test-pieces suggested on page 478 seem to meet the case very well. I do not quite know whether the author suggests that we should take the diagram literally, or whether, if it were possible, the test-pieces C and B could be taken from a chunk out of the rough, running more in the centre of the rotor. These rotors are very rough forgings, which are turned. I should imagine there would be enough left on the rough forging to take the B and C test-pieces more from the centre of the rotors instead of from the edge. I suppose that end is towards the top or bottom of the ingot. Should we not get a better average result if we could take it half-way down the bulk of the forging? In the statement that "the only justification for the built-up construction is for small rotors and when high-grade forgings are not obtainable and for single-phase work," I do not quite follow the reference to single-phase. Previous speakers have referred to the end-bell construction. I have not previously come across a case where it is suggested that this should be taken down to the shaft. It certainly appeals to me, if it is possible to make the end bell fit the shaft and take its position from the shaft rather than be carried on the end coils, which is in effect what happens when expansion of the cover due to centrifugal action takes place. I think it is a much better construction to carry it if possible from the shaft. That is not done in machines which have come under my care so far. With regard to ventilation, I am not quite sure

that we are on the right lines in putting the fan on the rotor. The fan must necessarily be of the induced-draught type; that is to say, where the shaft passes through the casing to the alternator there will be suction. I have machines in which there are fans on both ends of the rotor, drawing the air in and blowing it through both the rotor and the stator at the same time. That is to say, the same fans are used for both. In other machines there is a definite fan for the rotor and another for the stator, which I think is perferable, as a definite amount of air will be provided in each case. A large amount of air passes through these rotors, which is surprising in view of the small amount of space available. One firm of alternator constructors meet the difficulty of cooling the rotor coils by actually enclosing the winding in a thin metal case. This is dropped into a slot machined out of the solid with ribs so that the cooling air can pass actually in contact with this metal box. At the same time the slot is deeper than is necessary for the coil, the air can pass behind the bars and gets into intimate contact with the copper, and I believe the cooling effect is very good. The drawing-in of the air where the shaft passes through the case is to my mind very important. I have recently experienced a most interesting, although costly, break-down. We had a fire in an alternator which was apparently a case of spontaneous combustion. The machine did not break down electrically: the insulation was as good after the fire as before, but the machine could not be used as the nature of the insulation was gone. We found on opening the alternator that there was a considerable amount of deposit. The air ducts were filled up and the windings were in places thickly covered. We found traces of this throughout the machine. A wet air filter dealt with the air for this machine, and we had samples taken of the deposit from the sump and the baffles of the air filter, and also from each of the end windings and from the middle of the core. We also had samples tested of the lubricating oil used for the turbine, both fresh from the barrel and that which had actually been in the machine for 12 months. The deposit was chemically analysed, and the oils were tested in the usual way and the flash point taken. The report which we received proved conclusively that this deposit was not spontaneously combustible. What then made it burn? We also took samples of the deposit at these various points and tested their electrical properties in order to deduce from them their heat-conducting properties. We found that at the point where the fire commenced the deposit had an exceedingly high insulation resistance. The conclusion we have come to is that this deposit, wherever it settled on the coils, prevented the air which was in circulation from cooling the coils at such points at all, and that the temperature inside rose sufficiently to ignite the mixture locally. There are two remedies possible. One is to filter the air better, which is not very easy. The other is to prevent oil from getting into the machine. The only place where the oil could have entered the machine is through the holes in the casing where the rotor shaft passed through, and where the induced ventilation of the rotor will cause a suction and assist the oil to pass through. Possibly we shall eventually adopt an external fan to put the whole of the air inside the case under pressure and so make it blow out instead of in at such points as those under discussion. I think this is probably the reason we have not had this trouble with the old salient-pole machines fitted with an external fan, because we have a definite blow-out straight through the stator coil and no chance of any oil or mixture settling on the end windings. In the diagram on page 487 any oil that travels along the shaft will naturally creep up and settle on the fan blades and be circulated round and round in the end of the case to form an oil fog, which would give rise to the trouble. It is thrown off in a very fine vapour, and if when mixing with the air the latter contains very small particles of dust a fog will form which will cause a deposit on anything that comes in the way. I think the remark on page 488 with regard to the over-speed test is very true where the author says "for proving mechanical soundness the over-speed test fails." I think that failures that have occurred, and will occur, do so through fatigue and not through any sudden stresses put on the machine. The amount of over-speed which the author suggests is, I think, quite ample, viz. 20 per cent.

Mr. R. H. Campion: The point that impressed me particularly with regard to this paper was that the short, stiff shafts of the impulse machines stood as much chance of going down as some of the other shafts. The static deflection of a rotor under its own weight is generally taken as a measure of the stiffness, as the static deflection is reduced by increasing the shaft diameter or by reducing the distance between bearings. That seems to me to apply generally to page 473; and then on page 474 I was interested in the different methods of manufacture and turned up the Admiralty forging specification and noticed the difference. The Admiralty specification is that the sectional area of the body of the forging is not to be more than one-sixth of the original cross-sectional area of the ingot. This ensures a lot of forging work on it. There was a point with regard to annealed forgings of either mild steel or 3 per cent nickel steel having an ultimate tensile strength of 45 lb. per square inch, the elastic limit being 20 tons and the elongation not less than 20 per cent in 2 inches in the case of mild steel. Where nickel steel is used the elastic limit is not less than 21 tons per square inch and the elongation 22 to 32 per cent in 2 inches. These, I understand, did recently represent the standard practice.

Mr. R. C. Atkinson (*communicated*): During the past six or seven years very great strides have been made by metallurgists, and I think electrical power-supply engineers have for some time past had a feeling that alternator designers were perhaps not taking full advantage of this additional light which has been thrown upon certain problems closely related to those involved in the design of alternators. This paper makes it quite clear that if proper and scientific attention is given to all the materials used at all the points in the turbo-alternator rotor, and to the treatment of such materials from their birth through every step of their life till the finished rotor leaves the works,

the chances of subsequent failure are reduced to a minimum and should make for much greater reliability in the future. I am glad to see such emphasis laid on heat treatment of the steels used. Steel is not the simple material which engineers have rather got into the way of thinking it to be. It is a highly complex compound of different substances, sensitive in the highest degree to very small differences in treatment, and in future we have got to treat this material with due respect, if we want to get reliability and the best results out of it. I am also glad to see the fan question gone into in detail, even to the shearing stress on the bolts or rivets fixing the fans to the end bells. I am also glad to note that the author gives a fairly definite figure for the force which is to be used in pressing the rotor coils into the slots. I suggest that the actual force used should be recorded automatically at the time this and other operations of a like importance are carried out. The system of ventilation suggested by the author is very interesting, and I should like to know whether any machines of say 5,000 kw. at 3,000 r.p.m. fitted in this way are in operation. I do not like both slip rings being together, but rather one at each end, as it is safer. This would mean a greater span between bearings, which is probably the reason for putting them together. If they cannot be put one at each end, I think they should be kept as far apart as possible, and a fixed insulated barrier placed between. I do not see any mention of provision for linear expansion of the rotor conductors, which on a long rotor is appreciable.

Mr. H. E. Yerbury (*communicated*): All purchasers require the highest possible efficiency from turbo-generators consistent with safety, and, speaking generally, require the plant to occupy the minimum space, it follows that high speeds are the order of the day. That means that only the best and most suitable material should be used throughout, and the solid forging—properly treated—appears to be the most satisfactory for rotors of large machines. The author's statement that pure hard mica is the only material really suitable for insulating rotor coils, will I think receive general acceptance. I should like to ask him what material he uses for giving stability to the end windings exterior to the core. In the early days wood was very largely used, and during the past few years in many cases metal—usually aluminium—was favoured by rotor builders. It now appears that metal has certain undesirable properties, especially where wet air filters have been used, and many designers are now reverting to either wood or an inflammable moulded compound such as "Uralite." Instances are recorded where wet air filters have been fitted and moisture has passed on to the rotor, with the result that when the moisture was evaporated by the heat of the rotor certain salts were deposited, which eventually became a path for leakage, and trouble followed. Has the author had experience of this trouble? I think that many engineers will agree with the designer that non-magnetic material is preferable if it were possible for end bells. The author mentions the heating effect of stator leakage into steel end bells on short-circuit. Unfortunately, station engineers are often seriously concerned with this heating effect whilst the machines are not on short-circuit. The matter of high eddy-current losses in these bells should not be lightly regarded by designers. The importance of efficient ventilation is well understood. Will the author please say if he favours fans on the rotor for large units in preference to an external blower, and what power is taken in percentage of alternator output when the entire system of ventilation is effected by fans on the rotor. Many cases of inefficient ventilation have been traced to the churning of the air with obstructed passages in axial and also radial ducts, and also the breaking of fans through ignorance of the work these fans had to do. I agree that it is desirable to take away by a duct the discharge air, and no doubt now that rotors are capable of withstanding very high temperatures the heat units in the discharge will be made use of in the boiler house, thereby attaining the highest possible all-round efficiency.

(The author's reply to this discussion will be found on page 509.)

Manchester Local Section, 26 March, 1918.

Mr. J. S. Peck: On the first page the author refers to the reliance placed by engineers on strings and tape, and on the same page he says: "The conditions to be faced are most severe and the author doubts if they are sufficiently well realized by either user or maker." I do not think this is a fair criticism to apply to all manufacturers. The firm I am associated with have been making turbo-generators of large size and of different types for the past 15 years. We have used the laminated type, the plate type, and of late we have standardized on the solid forged type of rotor. In the whole of that period we have never had a serious mechanical breakdown. In one or two cases we have had minor troubles with balancing, but we have never had anything in the nature of an explosion or burst, either of the core itself or of the end rings. From the very first we fully appreciated the fact that the mechanical design of these very high-speed machines was, if anything, more important than the electrical design, and the calculations have been gone into with the very greatest care. I think the results obtained show that the mechanical designers have appreciated and understood the problem. The author goes in whole-heartedly for the solid forged rotor. We have also standardized on this type of machine, but, to be fair to the laminated and plate types, it must be admitted that there are certain arguments in their favour. If we could look into the inside of a solid forging, say 50 inche diameter, and be absolutely sure that it was homogeneous right through to the centre, there would be no question as to the advantages possessed by the forging: but we cannot look into the centre of the core and we must trust to the steel-maker to give us a first-class material. With the laminated or plate construction we are trusting to a material which may or may not be of such a high

class as the solid forging, but there is this to be said in its favour: every plate can be inspected, and, even if one or two should be defective, it does not make much difference because there are many other plates to help to carry the load, so that the chance of an accident is negligible. This, I think, gives really the gist of the whole situation with reference to the solid forging against the laminated rotor. So far we have had very excellent results with the solid forging, and the material obtained has been homogeneous and of very excellent quality. On some of our machines we have drilled holes straight through the shaft, and in other cases we have drilled holes at right angles to the axis through the core body, and have trepanned out suitable test pieces. These tests showed that while the ductility was not quite as good at the centre of the core, the tensile strength was practically as good at the very centre as at the outside. Tests of this kind have strengthened our faith in the solid forging. There is one remark the author makes which I do not understand. In referring to the different types of construction, he says the laminated rotor is to be used where a single-phase load or an unbalanced three-phase load is to be supplied. Our experience leads us to just the opposite opinion. We should never put in a laminated rotor for use with an unbalanced load unless a very heavy damper winding was provided. On the other hand we find that with the solid rotor the steel core itself acts as a damper, and the wedges in the top of the slots also act as a damper winding to carry current from one end of the rotor to the other. The next point I wish to touch on is the Appendix This rather takes me back to that unhappy time when we so frequently received specifications which said: "The armature of this machine is to be built up of laminations formed of the best Swedish charcoal iron, the current density in the winding is not to exceed 1,000 amperes per square inch, the density in the brushes is not to exceed so much," and so on. Then having specified in great detail how the machine was to be built, all responsibility for its successful operation was disclaimed. We designers and manufacturers have been asking for a long time to have the customer specify the conditions the machine is to meet, and then to leave to us the details of the design. I am glad to say that consulting engineers are coming more and more to realize that the designing of electrical machinery must be done by specialists who devote their whole time to this subject. I do not mean to say that the consultant should not satisfy himself as to the safety and soundness of the design, but rather that the details should be left to the specialist. If this specification in the appendix is intended to cover the machine which the author is prepared to build, I have nothing to say, but I do not think it is quite fair to tie down all manufacturers to these details. It is not at all certain that better materials than those specified will not be obtainable, and the manufacturers should have a free hand in adopting them.

Mr. A. D. Sloan: With reference to Fig. 12, the author states that the excessive heating was confined to the neighbourhood of the stator end plates and occurred chiefly on zero power factor, i.e. on short-circuit. I was discussing this matter with a station engineer about a fortnight ago and he raised the question of excessive heating of the end bell itself. I put forward the theory that with the stator leakage-flux rotating synchronously with the end bell no such heating would occur, but he said he had a machine in his station which would run at quite a normal temperature on the end bell with tank load, i.e. unity power factor, but with service conditions (about 70 per cent power factor) the steel end bell was excessively hot. I raised the question of unbalanced load, but the engineer maintained that his system was practically balanced, and repeated his statement that the temperature of the end bell was affected by the power factor of the load. Can the author throw any light on that? One other point in connection with the form of the end bell illustrated in Fig. 23: that is the general type advocated by the author in which the cylindrical portion and radial flange are all in one piece, and it is stated to be unnecessary to register the bell on the end of the rotor body. It occurs to me that as the end bell is likely to increase in diameter at full speed, if there is a tendency for it to become eccentric then holding it central at one end only is no guarantee that the other end will remain true. Again, it seems to me that this is a construction which tends to create high local concentration of stress at the point where the cylindrical portion is joined to the radial flange. The construction is not altogether unlike a sudden increase in shaft diameter. I admit that in the case of the end bell the stress is not an alternating one, but the arrangement certainly invites a very indeterminate concentration of stress locally.

Mr. J. R. Beard: It seemed to me in reading through the first part of the paper that in dealing with the pros and cons of the laminated rotor certain of its advantages were not referred to. Mr. Peck has already mentioned one point, namely, that with the laminated construction one has a definite demonstration that the material is sound throughout, which at present is not the case with a solid forging. Further points which occur to me, looking at it from the user's point of view, are that the delivery of a laminated rotor is likely to be more speedy and certain, particularly in war time, and that if, as is unfortunately occasionally the case with the solid forging, the test results necessitate its rejection there is a lengthy delay in replacing the forging, which is not likely to occur with the laminated construction. I notice the author lays stress on the fact that with a solid forged rotor the mechanical limitations are not in the body of the rotor itself, but in the crushing and side-slipping of the rotor windings and in the end rings. I should like to ask him whether consideration has ever been given to a rotor with a double winding, somewhat as shown in Fig. D. This construction could be carried right through into the end rings by using two of these concentric with each other, one carrying a portion of the winding and the other the remainder, the distribution between the two rings being proportioned so that each of them is stressed equally. It seems to me that by some such construction it should be possible, if desired, to increase the speed of any given rotor to a higher value than

with the present construction, and possibly even to the safe limit of the rotor teeth. The author mentions that steel wire is not a suitable material for retaining the end windings, and that although used in the early days it has been given up because of the difficulties of balancing. I assume that this only refers to its use when wound direct on the windings. The balancing difficulty could, however, be got over by winding the wire on a rigid former, preferably of non-magnetic material, the construction being similar to the wire-wound gun. If necessary it could also be further protected by an outside shell (carrying nothing but its own weight) against burning due to flashing-over from the stator in the event of a breakdown. With such a construction it would be quite easy to wind the steel wire only over the highly stressed parts of the former, leaving a non-magnetic gap between the wire and the rotor proper, and yet at the same time having the advantage of a solid construction right through. Alternatively, even if the steel wire completely covered the former it would give a much thinner magnetic film round the end ring than the ordinary

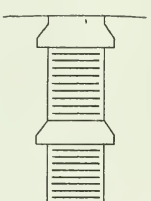


FIG. D.—Suggested rotor slot with double wedge.

construction, and consequently less magnetic leakage. The author once told me that manganese bronze was liable to disintegrate in a peculiar manner under certain conditions. I rather expected to see some mention of this in the paper, and I am sure it would be very useful if he would deal with the point in his reply. Since so much importance is attached in the paper to the effect of alternating stresses, I was rather surprised in referring to the specification at the end of the paper to find that no mention is made of alternating stress tests. In this connection I should like to ask the author to give us his views as to the value of the impact test. Opinions seem to vary considerably, as some manufacturers attach considerable importance to it while others do not use it at all. The suggestion in the paper that the yield point should be worked to in calculating factors of safety rather than the ultimate stress seems logical. I should like, however, to ask the author whether he considers the yield point to be as good an indication of the quality of the material as the ultimate stress, and if so, would he go so far as to pay practically no attention to the ultimate stress tests called for in his proposed specification.

Dr. W. Cramp: The author tries to put upon a scientific basis the questions which should be asked in a specification, to elicit answers from which the machines offered may be fairly judged. I agree with the warning which he sounds concerning disasters that might possibly occur owing to the neglect of some small matter; because it must always be remembered that a single turbo-generator giving trouble of a serious nature might not only cause a large amount of damage but even set the industry back for many years. One cannot therefore be too careful. With regard to specifications, I can say for my own firm that we try to put in such clauses as will avoid these accidents, without specifying details too particularly, because we wish to leave each maker free to develop on his own lines. For instance, we try to make it absolutely certain that we avoid running normally anywhere near the critical speed. We put in a clause limiting the peripheral speed and also a clause calling for a test at something like 30 per cent above the normal speed, and we reserve the right to call for test pieces taken from any portion of the machine. Even when all that has been done one still meets with the difficulty of deciding what material will give the best results and how to test that material. Factors of safety are really factors of ignorance, and they are so small now that we cannot afford to take risks due to material inferior to that upon which our calculations are based. It is very interesting to compare the author's remarks with those of another expert (Mr. Brearley of Sheffield), who, in a paper read before the Manchester Association of Engineers just 12 months ago on the subject of "The Testing of Steel," condemned any reliance upon the tensile test alone as a criterion. Now Dr. Barclay in his schedule of particulars to be furnished by manufacturers lays particular stress upon the tensile properties of steel, whereas Mr. Brearley says that the tensile properties alone are of no use and insists upon the use of the impact test in conjunction with the yield point and the maximum stress as the only safe guides. There are some figures given in the paper by Mr. Brearley which emphasize this point. They are very striking. He gives the results obtained from two pieces of steel taken from the same shaft and shows that while heat treatment left the tensile test unaltered it increased the impact figure more than thirty-fold. My point is then that the impact test should be included as one of the most important things in the schedule of particulars furnished by the manufacturer. [**Dr. Barclay:** The reason I did not put it in is that no steel maker will supply steel and guarantee that figure. It is not accepted as a reliable indication of what steel is.] There are steel makers, I think, who will guarantee an impact figure provided that we specify the impact machine to be used. Speaking for ourselves, in specifying tests, we shall try to enforce a combination of the two, believing that as a criterion of the true properties of steel either taken singly is liable to be misleading. The author lays some stress upon the work being finished smooth. A very striking example of this effect also has been given recently by Mr. Brearley. Tramway axles, which are rough machined, after they have been submitted to the stress of tramway

working for some time will break, and if carefully examined they will be found to have broken along the very fine thread left by the tool. The weakening which takes place due to the fine tool-mark is greater than one would suppose. That leads me to mention the question of punching out holes as against drilling. The author points out that a punched hole is very likely to have its edges distorted and therefore the whole plate becomes weakened. It has lately been proved beyond doubt that a plate which is drilled rapidly or bored rapidly is in as weak a condition as a plate that has been punched. I have found abroad that vessels intended for boilers, or for considerable internal pressure, often now have their rivet holes punched instead of drilled, although every specification for boilers in this country calls for the holes to be drilled and not punched. The fact is that if drilling is done slowly a better result is obtained; but if done quickly with modern drills it is doubtful whether the result of drilling is better than punching. In connection with a paper by Professor Field I have mentioned the importance of the relationship of slot depth to slot width, and I will merely refer Dr. Barclay to this * in connection with his remarks on the subject. It would be interesting if Dr. Barclay could tell us how he has arrived at the particulars given in Fig. 3. He shows there a curve which purports to connect the diameter of the rotor in inches with the revolutions per minute. I should like to know whether this curve is simply the result of a series of practical designs or whether the limit is the result of some theoretical consideration. I should like in conclusion to congratulate the author not only upon the curves given towards the end of the paper, especially in connection with heat treatment, but also upon the graphic means he has used to express relationships in other parts of the paper.

Mr. T. H. M. Swinburne: Referring to those sections of the paper entitled "The Choice of the Rotor Steel," and "Specification of Solid Forged Rotor," some of the author's remarks would seem to point in one direction and some in an opposite direction; so I would ask whether he would recommend an acid or a basic process for the production of the steel in the first instance. Then as to the tests, particularly for hardness, would not some of the tests adopted in the manufacture of cutting tools used in the production of munitions be admirably suited to the requirements? A third point is: has the author had any experience of tungsten alloyed with the steel for this specific purpose?

Mr. W. Kidd: I am in thorough agreement with the author in his advocacy of a solid rotor. The built-up rotor has always appeared to me to be a makeshift, and now that reliable large forgings suitable for rotors are commercially obtainable, the built-up rotor is a poor proposition for machines of high peripheral speed. Many generator builders in the past seem to have been rather doubtful about the large forgings, but they are gaining more confidence now, which is proved by the fact that most manufacturers now make their large and small rotors from solid forgings. The author has, with persistence, illustrated that most important fact that where there is stress there must be strain; and consequently due to the reversal of strain in each revolution, there is bound to be some relative movement between the parts of a built-up rotor. I believe that the superimposed stresses on the plate type of rotor are extremely small and within the elastic limit, but nevertheless the reversal of stress and strain is there. There is always the risk that due to faulty workmanship the strain may be greater than was anticipated, and although a great many machines no doubt run satisfactorily, in some cases they have worked loose. I think the question of whether or not a rotor will work loose is one to which the purchaser should give particular attention. The possibility of the rotor bursting must of course also be considered, but such instances are certainly more rare than those of rotors working loose. The author suggests that the purchaser should draft his specification in much greater detail than is done at the present time. I do not agree with him on this point. The design of a turbo rotor is the work of a specialist, and in the interests of future progress the designer should be given as free a hand as possible. It is necessary that the purchaser should clearly specify his requirements as to rating and certain other details which may be peculiar to his site. It is absurd for a purchaser to specify that the material must be of certain quality and not to state the maximum stress that may be put upon it. One is of absolutely no use without the other; it is the ratio between the two that is of consequence. I agree with the author that the purchaser is entitled to and should state in his specification that full details of the machine and particulars of the material and stresses should be supplied with the tender, and further working drawings should be submitted to him before any work is put in hand.

Mr. R. J. Roberts: I think we may say that the paper does not deal with the mechanical construction of a turbo rotor but rather with the steel to be used in its construction. The adoption of the solid rotor, for high speeds especially, is not at all unusual in these days; but there is one point which the author might have mentioned, viz. the question of uniformity in the steel. Could this uniformity be tested in any way in the piece without taking a sample from it? I believe the scleroscope is an instrument which might give the yield point straight away with some degree of accuracy. On page 482 the author mentions the discontinuance of the use of the wire bands; but he left out a most important consideration, the inequality of loading upon the band. I think that is the main reason why the bands have been given up. He also mentions end bells. Why do engineers call these "end bells" when they are rings? I think "cap rings" would be a better name for them. In his curves the author shows the relationship of stress and diameters and thickness of rings. I would ask him how these stresses in the cap rings, or end bells as he calls them, are computed. Are they computed from the average hoop stress or from the maximum stress obtaining in the rings, because the stress in the ring is not a uniform quantity at all? In Fig. 20 he shows a very small

* *Journal I.E.E.*, 1916, vol. 54, p. 182.

spigot ring between the steel and bronze. If that bronze ring were supported upon the end of the rotor there would occur a very high stress in that spigot flange. Again in Fig. 23, where the end of the ring is not supported at the rotor end, the stress that obtains in that ring is very high at the end nearest to the rotor where we get a bending stress in the ring which is, however, not necessarily purely a tensile stress. There is one point that has not been emphasized at all, namely, the ventilation and windage of high-speed rotors. On page 488 the author states that the fan loss is 20 per cent of the total windage. If that is so I am afraid he must get a very high windage loss indeed, for the fan loss on a machine of 5,000 kw., 3,000 r.p.m., 31 inches diameter would be something like 150 kw. [**Dr. Barclay :** No, about 24 kw.] It would be interesting to know how the author manages to keep the fan loss so low, because with a radially bladed fan the fan loss will be somewhere about 150 kw. if dimensioned proportionately to Fig. 23.

Professor G. G. Stoney : I agree with what the author says on page 474 as to the uncertainty of the critical speed of a laminated rotor ; we are not sure whether the discs are solid or whether they are loose. I had a case some time ago in connection with an impulse turbine which ran all right at first but after a time started to vibrate. We found that the spindle had been calculated as if the discs were fixed solidly on the shaft, and that gave a critical speed of 3,600 r.p.m., but if we supposed the discs to be loose the critical speed was only 2,900 r.p.m. and therefore it vibrated badly at 3,000 r.p.m. It was sent back to the works, the discs were taken off, liners were put in, and the discs shrunk on tight and it now runs all right. I agree with what the author says about solid rotors in small sizes being all right, but if they are absolutely solid we must be careful that the forging is not reduced too quickly down to the diameter of the spindle ends. It should be forged in a taper and the extra metal cut away. I have seen trouble due to this not being done. The case is rather different in large rotors for 1,500 r.p.m. which might go up to 5-feet diameter. I feel rather doubtful whether sufficient work can be put into the ingot in the case of such large diameters ; but that is entirely a question for the forge masters. I have seen disastrous results from forgings on which too little work has been done. If the forging is not well worked under the hammer or under the press it is always unreliable. Even when the main body is forged as a cylinder and put on a spindle as shown in Fig. 7 I am a little doubtful whether in large sizes sufficient work can be put on to make it really and absolutely reliable. The alternative method—I believe it has been a good deal used in America—of thick plates bolted together with bolts is a most ingenious one and I have always felt there was a good deal to be said for it. The bolts, of course, must be made of high-grade steel, and they should be turned down in the middle so as to give equal elasticity all along. These bolts must be screwed up with sufficient tension, and if a large factor of safety is allowed it should, to my mind, make a most reliable rotor. There must always be sufficient tension on the bolts to keep the plates solid under all conditions. Thick plates forged under the press are most reliable. They are forged from thick blocks to comparatively thin ones and get a great deal of work put on the material ; also the flow is in the right direction from the centre. I am inclined to think there is a good deal to be said for this construction unless the forge masters can guarantee that there is sufficient work put on very large rotors.

Mr. G. A. Juhlin : The author thinks the turbo-alternator has been responsible for the attention given to mechanical details. We should not overlook the work done by the engineers responsible for the early waterwheel generators, because the peripheral speeds of these machines are in many cases comparable with those of turbo-alternators ; and when we consider machines such as those for Niagara, which were built 24 years ago, I think it will be realized that considerable attention must have been paid to mechanical details. With reference to the laminated versus the solid rotor, there is one point which I think deserves some consideration. It is general practice to shrink the laminations on to the shaft with an allowance which will ensure that the laminations remain tight at the overspeed. This means that the stress due to the shrinking allowance will only be increased to a very small extent when running. This increase, which is due to the expansion of the shaft caused by centrifugal force, is, as mentioned, very small, and the stresses at the overspeed do not therefore increase in the same way as for the solid rotor. The author states that the bursting stress in the solid rotor is always lower than the tooth stress. This statement does not seem clear, as we have complete control of the tooth stress and can therefore make it what we wish. Moreover, with large diameters the bursting stress will be the governing feature as far as stresses in the rotor body itself are concerned. The laminated rotor certainly has the advantage as far as cost is concerned, and, in cases where the stresses can be kept down so as to leave a sufficient factor of safety, there is no clear reason for condemning it. In considering the mechanical features of high-speed turbo rotors, I think the question of insulation should have figured rather more prominently than is the case. The author states that there are great difficulties in keeping the coils from slipping sideways, no matter how well they may be braced. I agree with him up to a certain point, but I think he is unduly pessimistic with reference to this matter. It is possible by careful making of the coils, and by efficient bracing, to obviate any side-slipping. Fig. 2 illustrates clearly the pressure on the coils, but exaggerates the conditions as far as side-slip is concerned. The great pressure on the coils is in my opinion a factor against displacement, provided they are properly made and assembled. The latter point is of very great importance indeed in connection with the stability of the coils, because when the coils are pressed under heat and with the coils braced so as to keep the individual conductors in position, no difficulties whatever have been experienced. Referring to the suggestion made by Mr. Beard to improve the stability of the coils by dividing them into two portions by means of a wedge about the middle of the slot, I considered this

construction some time ago in order to determine whether any advantage would be obtained in the amount of copper which could be carried by the rotor. No advantage will be obtained, however, and I do not think there is any need to employ this arrangement to improve the stability. In connection with the number of slots, the author considers six coils per pole too many and that a better arrangement is to use less than this number. This question is of very great importance, and I do not think the conclusion can be accepted without some qualification. It is clearly undesirable to make the number of slots smaller than is required to obtain a mechanically sound arrangement, because the output of a given size rotor will be reduced if a very small number of slots is adopted, and it may be of interest to state that rotors having 16 slots per pole, and running at 3,000 r.p.m., have been in satisfactory operation for about $2\frac{1}{2}$ years without the slightest trouble. One machine was subjected to several dead short-circuits before leaving the works, and, as no displacement whatever could be detected, I think one may safely conclude that the stiffness and stability of the coils are quite satisfactory, because the conditions of this test were more severe than will be the case in actual practice when the inertia of the turbine rotor will reduce the momentary drop in speed caused by a short-circuit and therefore also reduce the stresses thrown on the rotor winding. The influence of the number of slots on the output of a given rotor is shown in Fig. E and, as will be seen, the output is reduced when the number of slots is reduced. It is also of interest to note that it is possible to use approximately the same size of strap with 32 slots as with 24, because less depth of slot is necessary to obtain the same heating when the larger number of slots is employed. These curves are necessarily approximate, as certain assumptions had to be made with regard to the wedges, but the error if any will be very small. As regards the diameter, I do not agree with the author that 32 inches is the maximum, and I have considered a case of a 35-inch rotor, as such a size may have to be adopted if very large outputs are to be obtained at 3,000 r.p.m. In connection with the stresses in the rotor, the author quite rightly points out the necessity of testing the material in the direction of the stress. It has been the practice of the company with which I am associated to specify tangential and radial test-pieces in addition to the usual longitudinal ones. Mr. Peck has already referred to some tests made to determine the condition of the material in the centre of rotors, and it may be of interest to give the details of the tests carried out. The following table gives the results and I think it will be agreed that these are very satisfactory:—

Test No.	Rotor Diam.	Ultimate Strength	Yield Point	Elongation in 2 in.	Reduction of Area
	In.	Lb. per sq. in.	Lb. per sq. in.	Per cent	Per cent
1	46	76,500	39,400	19·0	29·5
2	46	81,400	42,100	8·0	12·0
3	40	68,000	33,700	16·0	17·0
4*	40	70,000	28,520	15·5	19·0

The specification and steel-maker's tests for these rotors were as follows:—

SPECIFICATION.

	Test No.	Ultimate Strength	Yield Point	Elongation in 2 in.	Reduction of Area	Bend
		Lb. per sq. in.	Lb. per sq. in.	Per cent	Per cent	
Longitudinal from shaft end	—	75,000	37,500	20·26	—	180°
Tangential from body	—	75,000	37,500	20·25	—	120°
Radial from body	—	75,000	37,500	16	—	90°
STEEL-MAKER'S TESTS.						
Longitudinal from shaft end	1 and 2	85,200	60,000	30	54·8	180°
	3 and 4	82,000	52,000	30	50	
Tangential from body	1 and 2	86,400	46,800	26	36·4	180°
	3 and 4	96,000	44,000	25·5	36·4	
Radial from body	1 and 2	85,600	48,000	16	18·4	172°
	3 and 4	82,400	44,800	26	44·8	(broken)

The author recommends that a hole should be bored through the rotor when alloy steel is used. I think it is good practice to do so for all large and medium size rotors whether of carbon or alloy steel, as flaws are not unknown in carbon steel forgings. It is quite true that the stress is doubled by boring the hole, but as we cannot be certain that the material is perfectly sound in the centre, we may have the double

* This test piece was machined to 0·25 in. × 0·5 in. and bent round a 0·375 in. pin through 180°. It showed cracks on the outside, but was not broken.

(1) Test piece annealed before test. Fracture finely crystalline.
(2) Fracture coarsely crystalline.
(3) ditto
(4) ditto

stress if there should be a small cavity in or near the centre of the rotor. Moreover, it is preferable to have the sound and smooth surface obtained by drilling the hole than the sharp corners likely to be met with if there should be a flaw in the material. With reference to forging limits, there seems to be no difficulty in obtaining rotors up to 57 inches diameter from British steel-makers, and this may not represent the limit in diameter. The reduction in area given by one steel-maker for a 57-inch rotor forging was $2\frac{1}{2}$ to 1, and it was stated that this would be sufficient to ensure thorough working of the material. In connection with the design shown in Fig. 7, it should be pointed out that the stresses in this type will be very much higher than in the solid rotor, even with a small hole through the centre, and that a higher grade material will therefore be necessary for rotors running at 1,500 r.p.m. A diameter of 57 inches is sufficient to enable us to build units large enough to meet the demand for very large

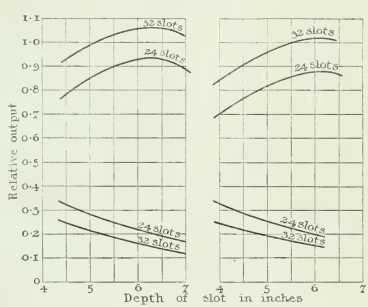


FIG. E.—Curves showing relative output of turbo-alternator rotors with different numbers and sizes of slots. Tooth stress constant.

units at 1,500 r.p.m., and there seems to be no immediate need for adopting the construction shown. I agree with the author that it is of great importance to avoid abrupt changes of diameters in the shaft. I do not think the construction shown in Fig. 21 would recommend itself to any engineer. It is our general practice to taper the shafts wherever possible in order to avoid abrupt changes, and in cases where oil throwers have been required by turbine builders these have been made loose for the same reason. With regard to ventilation, the author considers the ideal system to be radial ducts for the stator and separate axial ventilation for the rotor. This system is satisfactory for comparatively short machines, but for long machines it is inadequate, especially if small air-gaps are adopted. I quite agree that it is very important to ensure that the fans on the rotor are properly designed, but I cannot agree with some of the conclusions as regards design. I cannot understand the suggestion that the blades should be curved in a forward direction. In cases where an involute chamber is used, this arrangement of the blades is undoubtedly correct, but where a radial discharge is wanted, as in the case of a turbo-alternator, I do not think it is correct. The result of curving the blades forward is that the power required to drive the fans will be increased without any gain in the volume delivered. It is difficult to understand how the rotary motion will improve the cooling of the end connections when it is considered that no greater amount of air is passed.

I thoroughly endorse the author's opinion that high over-speed tests are not only unnecessary but also detrimental because of the possibility of injuring the insulation by subjecting it to the very high pressures caused by abnormal over-speeds. The specification given seems to me to be far too detailed to be suitable for a purchaser, because it would tie manufacturers down to narrow limits. Considering some of the details dealt with, I think it is more important to specify that the insulation should be as far as possible non-combustible than non-hygroscopic. With regard to the thickness, I do not think merely specifying the thickness will ensure satisfactory results, because there are many other factors to be considered in conjunction with the thickness before it is possible to judge as to whether the insulation is satisfactory. The limit given for the combined stress in the neck of the journal is in my opinion too low. Many machines have been running satisfactorily in service for years with much higher stress than that suggested by the author, and there is therefore no good reason for putting such a low limit on this stress. The author refers to the pressing of the coils in the slot. It may be of interest to state that this has for several years been the standard practice of the company with which I am associated, and has also been applied to the end winding. It would be interesting if the author would state whether pressing has been carried out in practice and what is his experience with pressed rotors, i.e. if any movements of the coils have been observed. With regard to the schedule of stresses, I do not think this will give a fair comparison of the excellence of different machines unless the method of calculating the various stresses is also specified. The question of the wire-wound rotor has been raised by some speakers. I think it should be made clear that the greatest difficulty with this type has been the damage caused to the band through arcs due to failures of stator windings.

Mr. J. A. Kuyser: The author gives interesting curves in Figs. 13 to 17 which illustrate the range of diameters for the different materials that are used in the construction of the end rings. The first of these curves gives the maximum diameter for nickel-chrome steel as 32 inches at 3,000 r.p.m., and in Fig. 3 this diameter is given for the maximum desirable at 3,000 r.p.m. I agree that this is for the present time a desirable maximum, as we can satisfy the present-day requirements of the turbine engineers without exceeding this diameter. It may, however, be necessary to build larger 3,000-r.p.m. generators in the future: 20,000-kw. turbines are now being built running at 2,400 r.p.m. in this country; whilst in Germany 15,000-k.v.a. 3,000-r.p.m. alternators have been built, and we should

try to beat this figure. In order to increase the present limits as to diameter we must obtain stronger material for the end rings. The author mentions 50 tons per square inch ultimate stress, 40 tons yield point, 18 per cent elongation, 50 per cent reduction, as physical properties for chrome-nickel steel. We have obtained from the United States 31-inch rings of the following guaranteed properties: Ultimate strength 73 tons per square inch, yield point 67 tons, elongation 15 per cent in 2 inch, reduction 45 per cent. These rings were made of chrome vanadium steel of the cylindrical type, and were shrunk on to a separate end disc. The advantage of this type of construction compared with the construction recommended in the paper is that the rings can be rolled on a tyre mill. This method is superior to the method of forging under the press; the material is worked more uniformly and the fibres are stretched in a peripheral direction, which is the direction of the maximum stress. These rings will

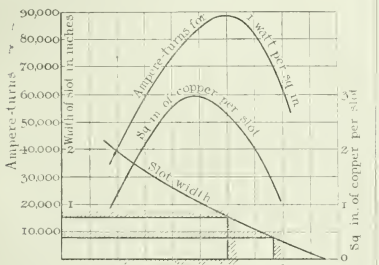


Fig. F.—Total field ampere-turns for 15,000 lb. per sq. in. tooth stress, 3,000 r.p.m., rotor diameter 35 inches.

allow a diameter of at least 40 inches or a speed of 32,000 feet per minute at 3,000 r.p.m. We have obtained from British steel-makers a large number of chrome-nickel steel rings of the following properties: Ultimate strength 60 tons per square inch, yield point 51 tons per square inch, elongation 15 per cent in 2 inches, reduction 45 per cent. These rings can be used up to at least 35 inches diameter, depending upon the amount of copper which is used. The next question is the possibility of increasing the diameter of the core itself, and I have drawn some curves which illustrate the possibilities of a carbon steel forging in this respect. The main point in obtaining a large output from the rotor at high peripheral speeds is to get as much copper in the rotor as possible without exceeding the tooth stress, bursting stress, and stress in wedge. The tooth saturation has only a small influence on the total flux, and has no influence on the operation of the machine. Fig. F, curve A, shows the amount of copper which can be accommodated for different sizes of slots; and curve B shows the total field ampere-turns. These curves are based on the two following formulæ, which will be found useful in stress calculations:—

$$(1)\quad 1-b=\frac{0{\cdot}42\times 10^{-5}\,(\mathrm{D\,N})^2\times a\,(1-a)^2}{\mathrm{S}\,(1-2\,a)};$$

(2) Depth of wedge $=0{\cdot}8\times 10^{-9}\,w\,d\,\mathrm{D}\,(1-a)\,\mathrm{N}^2$;

where a = (slot depth) ÷ rotor diameter; b = (slot width) ÷ slot pitch at base; D = rotor diameter; N = r.p.m.;

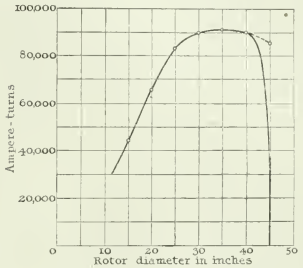


Fig. G.—Total field ampere-turns. 32/42 slots; 3,000 r.p.m.; stress 15,000 lb. per sq. in.

S = tooth stress in lb. per square inch; w = slot width; d = slot depth; all dimensions being in inches. The

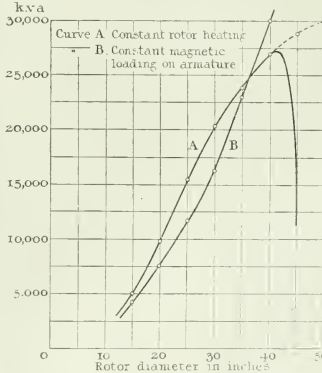


Fig. H.—Approximate k.v.a. output for 100-inch core length.

curves refer to a rotor of 35 inches diameter, and on this diameter we can obtain 90,000 ampere-turns. If we determine in the same way the maximum ampere-turns for other diameters, we can plot Fig. G, which gives the ampere-turns for different diameters. The

curve drawn in full takes consideration of all stresses, whilst the dotted curve takes no consideration of the bursting stress. A diameter of 45 inches corresponding to 36,000 feet per minute is the maximum for a solid steel cylinder without exceeding a safe bursting stress. In the case of a short rotor, it would be possible to increase the axial length in the centre of the core to reduce the bursting stress similar to a de Laval turbine wheel, and larger diameters could be obtained. A similar effect could be obtained by cutting some radial ducts at the periphery. For 40 inches diameter, slots are permissible which will accommodate the ampere-turns indicated in Fig. G. The output obtainable, equal to the product of the maximum ampere-turns and the magnetic section, is plotted in Fig. H as

only the iron and copper. By omitting the ducts we can get more copper in the rotor, which offsets the somewhat higher iron temperature; also the cost of machining is reduced. It is of course necessary to provide a fresh supply of air to the air-gaps, and for long machines as at present considered, this may be accomplished as indicated by the arrows in Fig. J. The air is delivered to the centre of the stator yoke from a separately-driven fan at a fairly high pressure, is carried down to the air-gap through the radial ducts, travels axially over the rotor, and escapes through the radial ducts of an adjacent section. This principle was, I believe, first used on a machine built 6 years ago in this country and was quite successful. The ventilation of the stator core itself can be taken care

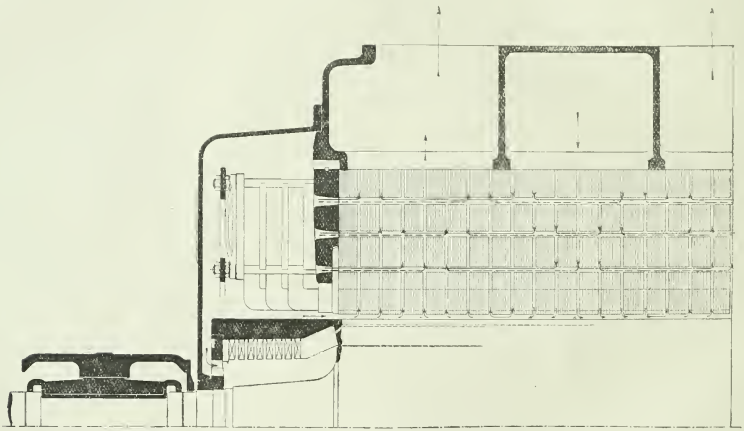


FIG. J.—31,250-k.v.a. 3,000-r.p.m. Turbo-alternator.

kilovolt-amperes for 100 inches core length. The maximum desirable diameter for a carbon steel forging taken from this curve is approximately 41 inches. Any increase above this will reduce the output. For a diameter of 35 inches we obtain 24,000 k.v.a. per 100 inches of core length, or 31,250 k.v.a. for 132 inches. I have worked out in detail the mechanical and electrical design for a machine of this size (see Fig. J). The stresses in the rotor are all below the figure corresponding to the safety factor recommended in the paper. The bursting stress is very low—11,000 lb. per square inch. This is due to the fact that there are no ventilating slots, all the rotor losses being dissipated from the surface at the air-gap and from the rotor end-connections. Ventilation of the rotor is of little advantage in machines of a large core length and a high peripheral speed, as the ventilation benefits

of by radial and axial air streams similar to a system which has been described before and which has been used successfully on a large number of machines. This method of ventilation would allow from an electrical point of view an indefinite lengthening of the machine; by doubling the length and providing more air inlets the capacity could be doubled without increasing the heating. The limit to the length would be the size of the bearing and the bending stress and twisting stress in the journal and end of core, and finally the bending stress in the centre of the core. In this direction I believe the present limits are capable of considerable extension. There are several large machines now being built of this general design. The author seems doubtful of the solid rotor for single-phase machines. Many single-phase machines have been built in the United States and in this country with solid rotors of

which I will mention the following: Several 5,000-k.v.a. 1,500-r.p.m. 25-period machines for the New York, New Haven & Hartford Railway with solid rotors; three 11,250-k.v.a. 1,500-r.p.m. 25-period machines for the Norfolk and Western Railroad with bolted plate rotors; a 14,300-k.v.a. 1,500-r.p.m. 25-period machine for the United Electric Light and Power Company with a bolted plate rotor. Several 3,000-r.p.m. single-phase machines of moderate capacity have also been built in this country with solid rotors. As a matter of fact, any three-phase machine with a solid rotor will carry something like two-thirds normal current as single-phase load even without a damper; whereas a laminated rotor without damper will develop trouble if the load is appreciably unbalanced. The author mentions some cases of magnetic instability due to insufficient saturation. In this connection I have known many machines of older design which had no saturation and no trouble was experienced. Perhaps the author will give us some more details of what actually happened in these cases. In connection with the safety factor, the author would recommend the elastic limit as a basis, if this could be more easily determined. I think the ultimate strength should also receive consideration. If the material has been somewhat overstrained above the elastic limit it is not ruined, but the elastic limit for a subsequent stress is actually increased, the material having been hardened. I know of cases where this hardening of the material through a slight deformation was usefully employed to increase the shrink-fit pressure of solid rotors shrunk on a through shaft. In these cases the bore had been expanded slightly by a large over-speed, and the fit obtained from such an expanded bore proved considerably superior to a normal shrink fit. The ultimate strength is more definite than the elastic limit and gives a basis on which we can judge the maximum speed at which the rotor would explode; and this factor of safety between normal speed and explosive speed is perhaps what we are most interested in. It has been proposed to use the average of ultimate strength and yield point as a basis, and this may be a good compromise. With reference to the bolted-plate type of construction described by Mr. Field, the author mentions a case of trouble with a 6,000-kw. machine. I can say from personal knowledge that no trouble has been experienced with any of the rotors built by the Westinghouse Company, and a sa matter of fact a machine of the size mentioned by the author has not been built by them. I believe this construction will have a field for large machines running at 1,800 r.p.m. and very large machines for 1,500 r.p.m.

Dr. S. F. Barclay (*communicated reply to discussions before the Institution and the Yorkshire and Manchester Local Sections*): In investigating the question of the critical speed of the unpierced-plate rotor, Mr. Field assumes that the plates are always in compression. If this condition obtains, then the critical speed must be substantially the same as with the solid forging, since the deflection in the body of the rotor is small compared with that of the shaft portion. Consequently any small difference in the deflection of the body of the rotor has an entirely negligible effect on the critical speed. This circumstance is so obvious that Mr. Field's proof is unnecessary. Fig. K shows the deflection curve of a typical 5000-kw. 3000-r.p.m. solid rotor.

The real problem, as to whether the plates are in compression or not in the presence of vibration, has not been dealt with by Mr. Field. My opinion—as already expressed—is that any vibration of sufficient magnitude to be appreciable, causing as it must an elongation of the bolts, must result in the plates losing their compression, for the reason that the plate area is so many times greater than the bolt area. With a 20,000-k.v.a. machine for the speed of 1800 r.p.m. the area of the plates in compression would be from 18 to 20 times as great as the area of the bolts in tension. Thus, in spite of the great initial tension that is applied to the bolts, a further extension of about 5/1000ths of an inch would result in the plates losing all compression. The vibration must be damped, for the reason that the time period of vibration with the plates in compression is quite different from that when the plates lose their compression. These deductions are in accord with the views put forward by Mr. Field in his paper (*Journal I.E.E.*, 1916, vol. 54, p. 68) when he stated and gave reasons in support of his statement that such a rotor has no true critical speed. It is to be regretted that he gives no reasons for repudiating his former views with which I was, and still am, in agreement.

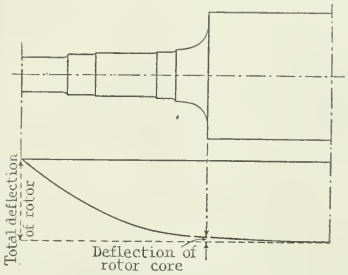


FIG. K.—Showing relative deflection of rotor core as compared with total deflection of whole rotor.

To deal with every specific case that may arise would need the scope of a somewhat lengthy book rather than that of a paper, and I had to content myself with reference to a few particular cases and deal with the remainder in a general way. With the construction of the cylinder shrunk on a through shaft, extreme cases may arise when the use of an alloy steel would be desirable. The objections, to which reference has been made in the paper, to employ an alloy steel for a solid forging would not arise with a hollow cylinder forged on a mandril or with a cylinder from which the core is trepanned before heat treatment.

As explained in the paper, the maximum diameter of 51 inches for the solid rotor represents the capacity of most steel-makers' plant and is not an inherent limitation. For instance, for a 50,000-kw. alternator at 1,500 r.p.m. I would recommend the use of a solid rotor having a diameter of about 56 inches. Such a forging could be made quite satisfactorily by the firm with which I am associated, and probably by some other large steel-makers, but no doubt there are many manufacturers who could not produce such a forging, weighing as it would about 70 tons. The maximum stress in such a rotor forging need not exceed one-eighth of the ultimate strength of the material, and the construction would therefore be safe in the extreme. With this high factor of safety it would be entirely satisfactory for the steel to be in the normalized and annealed condition, although I would prefer to have it oil-hardened and tempered for the reasons given in the paper.

Mr. Field quite properly draws attention to the complicated nature of the stresses in the end bells. There is no difficulty, however, in assuming conditions worse than can arise and in proportioning the end bells accordingly. In questioning the advisability of registering the end bell on extensions of the rotor wedges, Mr. Field has overlooked the great strength of the wedge extension considered as a cantilever. In the average case of a 5,000-kw. 3,000-r.p.m. rotor, before the extensions of the slot wedges could take a permanent set a load of 60 tons would need to be applied to them. The wedges thus constitute a very excellent register, and this reasoning is borne out by the uniformly perfect results that have attended the use of the construction in a great number of cases.

Mr. Field makes the curious error of assuming that the permissible stresses for manganese bronze and nickel-chrome steel that are given in the paper must necessarily be present. As a matter of fact, the loading on the two metals at the joint is substantially the same, and in the absence of resisting influence the stress in the two must be the same. With equal stress the manganese bronze must open more than the steel, and if a narrow lip of metal is tending to prevent the manganese bronze opening (elastically), then surely there must be a tendency for the lip to be over-stressed. I have seen two cases of failure unquestionably due to this cause.

In his able investigation of the unpierced-plate construction, Mr. Field commits the oversight of applying Hooke's law as a universal truth, whereas it is applicable only in the case of an elementary structure. Thus the extension of the nickel-chrome steel bolts gives absolutely no indication of the maximum stress in the bolts. The extension may indicate a low average stress when the stress in the screw threads may have reached a dangerous value. As explained in the paper, the weakness of the construction lies in the screw thread, and yet Mr. Field makes no reference whatever to having investigated the distribution and concentration of stress at different parts of the nut and bolt threads. Fig. L shows the variation in stress between the top and bottom of the nut which results from the elastic yielding of the bolt and nut. In calculating the curve it has been assumed that the nut and bolt threads have an absolutely accurate pitch. Consideration, however, must be given to the enormous importance of having extreme accuracy in the pitch of the screw threads. Such a small error as less than half a 1,000th of an inch in the pitch of the screw thread of the nut as compared with the bolt could result in the threads being stressed to the breaking point when the extension of the bolt is indicating a bolt stress of only 40,000 lb. per square inch. The brilliant discovery of Dr. Coker that the intensity of stress can be made clearly apparent by passing polarized light through an isotropic material has been applied by the author to show the distribution and concentration of stress in screw threads, which is present even with a perfectly accurate pitch, and the enormous stress that can be caused by the smallest error in the pitch.

I regret that owing to the present difficulties of reproducing photographs the results cannot be shown here, but I would refer Mr. Field to Mr. Stromeyer's

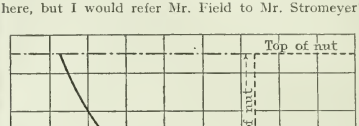


FIG. L.—Distribution of stress in screw threads of nut and bolt having exactly correct thread pitch.

recent paper on the subject and to the valuable work carried out by Mr. Rowland of the Technical School, Leicester.

Mr. Field's statement that with the unpierced-plate construction there are no initial stresses except intentional stresses, shows that he has not given this vitally important matter his consideration.

The most important of Mr. Field's interesting remarks is that for all outputs at 3,000 r.p.m. he concurs that the solid rotor represents the best construction. With larger solid rotors for lower speeds, the stresses in the forging decrease, until for an output of 50,000 kw. at 1,500 r.p.m. the maximum stress need not exceed 5 tons per square inch. Any competent forge master would tell Mr. Field that to make a 56-inch diameter rotor for a maximum stress of 5 tons per square inch is a simpler matter than to make a 31-inch diameter rotor for a maximum stress of 10 tons per square inch. Thus, carrying Mr. Field's own statement to its logical conclusion, shows his agreement with the construction he criticizes. Much of the criticism of the solid rotor is based on lack of knowledge of the rudiments of metallurgy. Thus Mr. Field makes the statement that the centre of a large forging is glass-hard—a statement which every metallurgist knows to be the exact reverse of the truth. If steel could be cooled

infinitely quickly from a temperature above the upper critical range, it would be preserved in its gamma state, i.e. its hardest state. With a carbon content of the kind in question such hardness would not be great, and the steel could be machined and, compared with glass-hard steels, would be soft indeed. If the steel could be cooled infinitely slowly from above the upper critical range, then it would be transformed entirely into the alpha state, i.e. the softest state in which it can exist at ordinary temperatures. Thus an oil-hardened forging varies from a maximum hardness at the surface to a minimum hardness at the centre. Further, it must not be overlooked that, after oil-hardening, the forging is tempered to relieve stress and to remove any undesirable degree of hardness. The tempering consists in raising the forging to about 550° C.—the exact temperature depends on the carbon content—and then allowing it to cool slowly.

Mr. Clough's statement cannot be accepted that, if high-tensile steel wire is satisfactory, it follows that steel hardened by cold-rolling must be equally satisfactory. Cold-working if carried out to any appreciable extent is essentially unsatisfactory, for the reason given in the paper, viz. that locally the cold-working may be carried too far and incipient internal

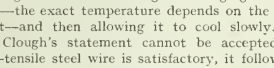


FIG. M.—Internal fractures in cold-drawn wire.

fractures caused. The pull required to draw wire through the dies is great—greater than the stress to which it is subjected in service if a satisfactory margin of safety is provided—and in this way every inch of the wire is automatically tested and any defect is at once shown by the wire breaking. With a cold-rolled sheet, any incipient fractures that may have been caused cannot be detected, it being impossible to find them by testing and equally impossible to detect them by observation, since they are most likely to occur inside the material. The nature of the minute internal fractures that may be caused when wire is drawn are shown in Fig. M. As already explained, if such a fracture developed in the steel wire, it would break whilst being drawn. There is the further essential difference between the two cases that the cold-worked sheets are annealed at a low temperature, giving rise to the possibility, with a low carbon content, of rectangular brittleness, whereas the wire is not annealed and has such a composition that rectangular brittleness cannot occur.

There is no reason why the laminated rotor should give better cooling than the solid rotor, indeed, having regard to the fact that the air ducts can always be placed immediately under the rotor coils, the solid rotor is really better cooled. By omitting the end-bell support down to the shaft, the rotor end coils can be much better exposed to the ventilating air. Such a construction does not appear to be desirable, but better cooling is undoubtedly obtained, and Mr. Clough's statement is probably influenced by some difference of construction of this kind rather than by a direct comparison of the solid with the laminated rotor.

It is interesting to hear that Mr. Clough has had such complete success with the construction he employs. I should like to make it quite clear that I concur that with either the laminated or the unpierced-plate construction, if properly carried out, the chance of failure is very small; and if failure were attended by no worse consequence than the replacement of material, I would agree that either construction is to be regarded as satisfactory. As I endeavoured to show in the paper, however, on account of the enormous forces present, a failure may be attended by the most dire consequences, involving even danger to life. For this reason I advocate the very best construction rather than one that appears to be good enough.

In reply to Dr. Smith, I have not encountered cases of rolled sheets being thicker at the centre than at the edges. There should be no difficulty in producing sheets of uniform thickness, and it is possible that the case Dr. Smith cites was due to using rolls of insufficient stiffness. I have seen several instances of laminated cores being thicker at the bore than elsewhere, though not to the extent mentioned by Dr. Smith, but that was due to the plates having big burrs round the central hole and, further, to their not having been assembled in the order in which they were punched. Dr. Smith's authoritative remarks on the importance of the correct exciting-coil distribution are very interesting.

Mr. Everest has read into the specification given in the paper a meaning that it was not meant to convey. To give a typical specification for the guidance of the customer's technical adviser is surely not exactly the same thing as to suggest a hard and fast standardized construction, as Mr. Everest states. It is outside my province to deal with the consulting engineer's duties, but I nevertheless hold the view that in the event of a turbo-alternator being wrecked, it is probable that the consulting engineer will be amongst those who will be interviewed. If the consulting engineer should feel that one of his duties is reasonably to safeguard his clients against such a disaster, then it would be necessary for him to issue a specification of the type indicated and obtain information concerning the stresses and the quality of the material employed, in the way suggested. The exact form of the specification, of course, would vary according to the particular design in question, but the main features of the specification suggested would apply to all cases. For the consulting engineer to issue a specification that will ensure sound mechanical design no more standardizes the design and cripples the development of high-speed alternators than does painting the Plimsoll line on the side of a ship standardize ships and cripple shipbuilding development.

Mr. Everest and several other speakers overlook the enormous difference between a failure of ordinary electrical machinery and a failure of a large high-speed alternator. It is the experience of everybody who runs electrical plant on a big scale that mechanical failures do occur from time to time. The percentage of such failures with good plant is small, and breakdown usually occurs after years of arduous service. The

breakdowns cause nothing but relatively small material damage, and if occurring, as they usually do, after some years of service, they are more or less taken for granted. What has to be borne in mind is that a mechanical failure of a large high-speed alternator will most probably cause tremendous damage and endanger life, and therefore cannot be tolerated in any circumstance. Now the factor of safety with these large high-speed machines is less than with ordinary machines that do fail from time to time; and if such machines are nevertheless to have superlative excellence, it is obvious that nothing but the most perfect materials and the very best design must be employed. Unless the development of these high-speed machines is to receive such a set-back as it would do if even only a very few disasters take place, I hold that every manufacturer should adopt the very best construction and not postpone doing so until he has had some failures. In short, I do dogmatize, but it is not for any particular design and only for excellence.

I cannot see that there is anything inconsistent in the statements that the modern turbo-alternator rotor is a high-class production and that all designs are not equally good.

In answer to the other charge of inconsistency that Mr. Everest makes, I wish to make it clear that a central hole in either stamping or forging is not *ipso facto* undesirable. It is simply a question of the quality of the material employed and the stress to which it will be subjected, and there is nothing inconsistent in saying that a cold-worked sheet with a central hole may be unsatisfactory for a particular design and a hollow high-grade steel cylinder forged on a mandril may be satisfactory for another design. Further, there is nothing incompatible in the statement of the well-known facts that the hoop stress in a cylinder is doubled by piercing it, and that the hollow cylinder for large sizes is a desirable construction.

In reply to Mr. Taylor, I agree that with two-pole machines appreciable saturation can be provided in the rotor core as well as in the teeth, even with a solid rotor, but for four-pole designs it is difficult to have much saturation elsewhere than in the teeth, unless a core with a central hole is used. Regarding ventilation, it is my experience that even a small channel if it be smooth and if a fairly high air velocity be used, never becomes choked with dirt. The dirt seems to accumulate appreciably only where there are pockets and only where the air velocity is low.

Mr. Selvey's statement that laminated rotors are used only for very small machines and Mr. Field's statement that they are of historic interest only, do not agree with the information given by other speakers. Further, I understand that some of the very largest machines now being made have rotors of this type. I agree with Mr. Selvey that there is something unsatisfactory in having to stipulate "an approved maker" for the forgings. Unfortunately, there is no alternative unless the customer can send an expert chemist, metallurgist, and forge master to supervise the whole of the operations at the steel works. I endeavoured to show in the paper that mechanical tests alone may fail to detect unsatisfactory material. The only real safeguard is to purchase the steel from a high-class maker of repute and then to test it exhaustively in the way suggested.

With the type of end bell advocated in the paper, there would be no difficulty in placing the holes in the discs in line with the ducts beneath the windings. My experience is that dirt does not accumulate in such ducts to an extent that is detrimental. The real danger is that the dirt may lodge in the rotor end-windings, whence it cannot be removed except by removing the end bells. It is essential that the air filter should be effective in removing dirt from the air, and the duty of the filter should be lightened as much as possible by drawing on the cleanest air available. Frequently one sees the intake into the filter placed near ash heaps and coal plant—an arrangement to be strongly condemned.

In my opinion Mr. Selvey's criticisms of the axially-ventilated rotor are not well founded. Whether axial or radial ventilation be employed, there must be a difference of temperature between the points where the air enters and leaves the ducts. Such a difference of temperature is in itself without importance. What does matter, however, is that the hottest part must be cool enough; and that result can be effectively obtained with the axial ventilation. I have apparently not made my meaning sufficiently clear with regard to the shape of the fan blades. I meant to point out simply that the blades should be shaped so that the air enters without shock, and that the blades should be radial where the air leaves the fan. The blades should be curved in that way only, and certainly should not be bent forward of the radial line where the air leaves the fan.

In reply to Mr. Shepherd, for any rotor the forge master is always careful to select an ingot of sufficient size so that the amount of work that has to be done on it ensures a thoroughly satisfactory rotor. To relieve the forging of initial strain, it is thoroughly annealed after forging, is rough turned before oil-hardening, and finally tempered. As explained in the paper, the oil-hardening has the maximum effect at the outside of the forging and the minimum effect at the centre; but for all sizes of rotors so far considered, i.e. up to 50,000 kw., the condition of the steel at the centre is quite satisfactory. Further, it is to be remembered that the greatest stresses are located in the teeth at the part where the oil-hardening has full effect.

Concerning the ventilation of large alternators, there is no difficulty in arranging for the necessary volume of cooling air. Water-cooling is very attractive, but it has its disadvantages. One of the not so obvious disadvantages is that the cooling water itself has to be circulated and cooled unless there is a plentiful supply of clean water available.

In reply to Mr. Hefford, the condition of the steel in the largest rotors can be fully examined by trepanning rods from the core. I have had rods removed in this way from large rotors and find that the tensile strength and ductility at the centre of the rotor is almost as good as at the end of the shaft. The crystal size is somewhat larger at the centre than at the periphery,

but is still quite satisfactory for the purpose, as would be expected since the steel there cannot be worse than in the normalized and annealed condition.

All the turbo-alternators made by the firm with which I am associated are short-circuited at the terminals on test with entirely satisfactory results. It is entirely a matter of providing sufficient leakage reactance to limit the short-circuit current to a reasonable value and of adequately anchoring the stator end-connections.

I fully concur with Mr. Hefford that there should be no need to draw attention to the inadvisability of punching holes in highly stressed laminations, but such methods are still employed. In reply to the question Mr. Hefford very properly raises concerning the position of the test pieces, whether taken from the ends or the centre of the core the results are just the same, since the oil-hardening has full effect at the part of the greatest stress, i.e. the bottom of the tooth.

My reference to the use of laminated rotors for single-phase work was meant to be non-committal, since opinion on the subject is divided. With the solid rotor the steel offers an excellent path for the flow of the damping current induced by the pulsating armature reaction, but some designers hold the view that it is preferable to confine such currents to the high-conductivity path of the slot wedges. It is my experience that the solid rotor is entirely satisfactory for such work and is therefore preferable. For three-phase work this problem does not arise, since the stator magnetomotive force revolves synchronously with the rotor, and varies only in the ratio of $\sqrt{3} : 2$ and has a zero third harmonic. For two-phase work the problem arises in a slight degree, since the armature magnetomotive force varies in the ratio of $1 : \sqrt{2}$, and has a third harmonic equal to 11 per cent of the fundamental.

In reply to Mr. Hefford's criticism of the axially-ventilated rotor advocated in the paper, it is to be explained that if any oil vapour should be drawn into the rotor fan, it does not enter the machine but is blown into the exhaust. I fully appreciate Mr. Hefford's reference to this matter, since if oil vapour enters the machine it tends to assist the retention of dirt. I invariably provide a close-running seal between the end casting and the shaft by fitting knife-edged scrapers.

I am inclined to think that the fire described by Mr. Hefford was caused, not by spontaneous combustion, but by dirt having bridged across the end connectors and a local short-circuit having developed. Several such incidents have come to my notice: in some cases the flow of current removed the dirt that caused the trouble, and after the mishap the insulation both to earth and between turns was excellent.

In reply to Mr. Campion, forge masters are agreed that the results are quite satisfactory if the ingot from which the forging is made has a minimum area double that of the forging.

The point that Mr. Atkinson raises concerning the location of the slip-rings is interesting. For a radially ventilated machine, with or without axial stator ventilation, I agree that it is preferable to have one ring at each end. With the axially ventilated rotor, however, there are advantages in having the two slip-rings at the end remote from the rotor fan. As already explained, at the end where the rotor fan is located, the oil vapour is positively prevented from entering the machine; and if the two rings are placed at the other end the distance between the bearings and the end casting of the stator is increased and thus the probability of oil vapour entering at that end is reduced. Another advantage is that the space required for the rotor fan and for the extra air passage is roughly equivalent to the space required for the slip-rings, and so the rotor core is symmetrically disposed with regard to the bearings and the curve of deflection is uniform. Every engineer must agree with Mr. Atkinson's informative remarks concerning the need for full consideration of every point of the design of these difficult high-speed rotors.

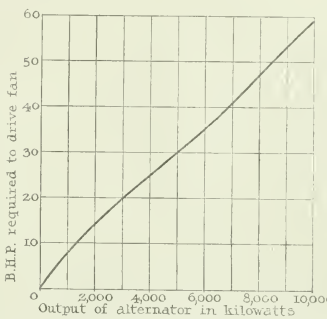


FIG. X.—Showing approximate relationship between output and power required for ventilating fan.

In reply to Mr. Yerbury, my experience is that well-dried red fibre is a very satisfactory material for wedging the rotor end windings. Free moisture carried over into the alternator is not an infrequent trouble with wet air filters. In my experience the most common cause is insufficient margin between the rated capacity of the filter and the actual volume of air flowing. Most makers seem to rate the filters rather high, and if no margin is allowed, the air velocity may be too great and free moisture be carried over. With filters of the type that have eliminator plates on which water is sprayed, it is vitally important to see that the sprayers do not corrode and that water at the right pressure is supplied to them. Too much or too little water on the plates causes free moisture to be carried over. With spray filters of the type that has the spray directed into the filter, any corrosion of the sprayer results in a jet of water rather than a spray being formed, and so water is carried over and, further, the air is not properly cleaned. In large towns and particularly near steel works, there is a

certain amount of sulphur in the air and, as the water is used over and over again, sulphuric acid is formed which attacks the fine edges of the sprayers. One is apt to overlook the enormous weight of water that is cleaned by the filter in a week. In the case of an average 5,000-kw. machine, the weight of air used per week is fully 6,000 tons. If the water is renewed only once a week, as is usual, it will be seen what a small percentage of sulphur in the air can make the cleansing water actively acid. It is desirable to have the cleansing water analysed to find if acid is being formed, and if it is, a sufficient quantity of soda ash (sodium carbonate) should be added when the clean water is run in to ensure that the acid formed during the week will be neutralized.

For machines for small and medium outputs, I am in favour of having the ventilating fans self-contained with the rotor; but for very large machines it may be desirable to employ a separate fan.

The fan power required varies considerably with differently designed alternators of a given output. The approximate relationship between the alternator output and the fan power required is given in Fig. N.

Mr. Peck's statement that the soundness of the rotor laminated plates can be determined by inspection must be very considerably qualified, since such an inspection would need to include taking micro-sections at different parts of the plate in order to verify that the cold-working had not caused incipient internal fractures. An examination that is restricted to looking at the plate would, of course, be quite useless to safeguard against the real danger to be met, namely, internal fracture.

I concur with Mr. Peck's views concerning the employment of the solid rotor for single-phase work, which point has been dealt with earlier in my reply.

In reply to Mr. Peck's remarks concerning the specification given in the paper, I agree that all matter of detail should be left to the maker, and the consulting engineer's specification should be limited to ensuring safety and soundness. Mr. Peck and I are therefore in agreement as to principle—the detail concerning which we differ cannot be discussed, since Mr. Peck makes no specific reference.

The case of the end bells of a turbo-alternator becoming excessively hot when run on inductive load, as mentioned by Mr. Sloan, is very interesting. It would be difficult, however, to determine the cause in the absence of information concerning the electrical and mechanical design. I presume that Mr. Sloan satisfied himself that the heating was really in the bell and not in the rotor copper; the heating would of course be considerably greater on 70 per cent than on unity power factor. In criticizing the type of end bell advocated in the paper, Mr. Sloan overlooks the great strength and stiffness of the extension of the rotor wedges to which reference has been made earlier in my reply. Where the radial flange of the suggested end bell joins the cylindrical portion, there should be a gradual change of section. As is explained in the paper, the greatest stress in the bell is at the end remote from the core, and to be able to strengthen it by adding the radial flange constitutes a very desirable arrangement.

Mr. Beard's suggestion to supplement the slot wedge by a similar wedge located half way down the slot is ingenious, but I believe that difficulties would arise in practice. I have on various occasions considered Mr. Beard's other suggestion to use a non-magnetic material for the end bells reinforced with high-tensile steel wire. The main difficulty to be faced is the considerable difference in elastic extension for a given load between the non-magnetic material of the bell and the steel wire. Further, reference to the curves given in the paper will show that even when carrying nothing but its own weight, the non-magnetic material can be employed only for quite small rotors.

The point Mr. Beard raises concerning the peculiar behaviour of manganese bronze under certain conditions was accidentally discovered by me some little time ago. I found that when a high-grade manganese bronze was being stressed, if the surface was touched with a little molten solder, the solder ran into the solid metal like ink runs into blotting paper. A micro-examination showed that the solder had flowed in between the crystals and had almost entirely robbed the inter-crystalline cement of its strength. Material that was tough and ductile before being treated in this way became perfectly brittle. I made experiments with many different qualities of yellow metal and found that most of them were not subject at all to the action, which seemed most liable to occur in cheap brass and in the highest grade manganese bronze. I understand that this remarkable quality of certain yellow metals is not well-known and I should like to take advantage of this occasion to warn members to make a careful experiment before employing any yellow metal that has to be soldered and carry stress.

In reply to another point raised by Mr. Beard, it is hardly practicable to specify alternating stress tests since they take a long time to make and such very different results are secured with different types of machines. Moreover, for a given composition, if the steel is sound, as can be verified more readily by other means, the satisfactory behaviour under alternating stress would follow as a matter of course.

I will deal with the question of the impact test in my reply to Dr. Cramp.

In reply to the last question raised by Mr. Beard, it is my opinion that the ultimate strength of the material should always be determined, for the reason that although the yield point should be the basis on which permissible stress is calculated, yet the relationship between the ultimate strength and the yield point is a valuable indication of the condition of the steel. For instance, a normal nickel-chrome steel that has a yield point of 40 tons to the square inch has an ultimate strength of 50 tons to the square inch. If the test showed, however, that although the yield point was 40 tons, the ultimate strength was, say, 60 tons, then the manufacturer would know at once that there was something wrong with the steel, which information would not be forthcoming if the yield point alone had been determined.

In reply to Mr. Beard's question concerning the

impact tests and to Dr. Cramp's remarks on the same subject, I will state briefly the present position. The tensile test is a valuable test in so far as it indicates the class of the steel and the state of the heat treatment, and the impact test can certainly not be used in substitution of the tensile tests for obtaining this information. Where the tensile test fails, however, is that, in certain abnormal conditions of the steel, results obtained may indicate that the steel is satisfactory, whereas really it is not. Dr. Cramp is misled apparently in thinking that this peculiar behaviour of steel applies to all steels, whereas such is not the case. The impact test is not proposed for carbon steels and is used only for alloy steels and, in particular, nickel chrome. Although it is generally agreed that the tensile test fails to indicate certain conditions of weakness, it is by no means generally agreed that the impact test satisfactorily meets the case. As Dr. Cramp points out, when the tensile tests are quite satisfactory, the impact figure may definitely show that the steel is unsatisfactory, but what Dr. Cramp does not state is that a high figure for the impact test may be obtained when the steel is unsatisfactory. At the present time, many engineers discredit the impact test completely, and some manufacturers would not supply steel that had to comply with such a test. Further, no one having experience with the impact test and knowing the very variable readings obtained would even dream of using it, not as a supplement to, but in complete substitution of the tensile test. To the experienced man a study of the fracture that is caused by impact gives full information as to the condition of the steel, any inter-crystalline weakness being clearly apparent. It will be seen, therefore, that the tensile test has to be specified, and the only point in doubt between Dr. Cramp and me is as to whether the impact test in addition should be specified for the nickel-chrome steel for the end bells. For the reasons given, it is my opinion that at the present time it is preferable to specify that the steel should be broken by impact and the fracture studied, rather than that the number of foot-pounds required to cause the fracture should be accepted as the criterion.

I fully agree with Dr. Cramp that plates can be damaged by drilling them too rapidly, but I can hardly agree with what Dr. Cramp implies, that since some drilling is done improperly, all drilling might quite well be replaced by punching. As to whether a plate has been damaged or not by the drilling, is fortunately not a matter that need remain as one of opinion, since a micro-section will readily demonstrate the extent of the damage. This interesting subject, however, is irrelevant to the discussion, since it has not been suggested that drilling shall be substituted for punching, but that the material damaged by punching shall be removed.

In answer to Dr. Cramp's question, the curve given in Fig. 3 is simply the result of a series of practical designs and does not represent any inherent limitation.

In reply to Mr. Swinburne, the acid process is generally used for high-grade work in this country. The best work by the basic process would probably be suitable for small and medium-size work, but for large rotors the acid process has undoubted advantages. A great deal of research and experimental work has been done with steel having different percentages of tungstens, but I do not know that such steels have so far been proposed for work of the kind in question.

In reply to Mr. Kidd, as already mentioned, my only object in suggesting the specification was to ensure mechanical soundness and we are therefore substantially in agreement.

In reply to Mr. Roberts, my experience of the sclerоscope is that it may give very erratic results. The instrument consists of a small steel weight that is dropped upon the surface under test, the weight being kept to a true course by falling down a glass tube. The lower end of the weight is provided with a sharp point either of hardened steel or a diamond. The hardness on the scale of the instrument is measured by reading off the height of the rebound that is obtained. The sharp point on the weight actually indents the surface of the steel under test and thus does a small amount of work on it. It will be seen, therefore, that the actual height of the rebound is a function of the elastic properties of the material under test and of the material of which the weight is made; also it is a function of the frictional resistance between the falling weight and the guide tube, and further is a function of the work done in causing the indent. The instrument thus measures a very complex function of different properties, and the erratic results that are sometimes obtained are to be expected. An instrument that is now being very extensively employed for rapidly testing metals without having to remove a test piece from the bulk, is the Brinell machine. With this machine a given load is applied to a steel ball, the diameter of the curved indent is measured under a magnifying glass, and the hardness number is read from a table. For steels of similar type, the hardness number determined in this way agrees very closely with the ultimate stress determined by tensile tests. By the employment of this machine it is therefore possible to determine the tensile properties of the steel at any part of the periphery of the rotor.

Concerning the stresses in the end bells, in calculating the curves given in the paper the concentration of the coil loading was taken into account, and also allowance was made for the concentration of stress at the inner periphery. For a 5,000-kw. alternator for 3,000 r.p.m. with a 31-inch diameter rotor, the fan loss would be about 24 kw., and the total windage loss including the fans would be about 100 to 110 kw.

In reply to Professor Stoney, it should be pointed out that there is no inherent limitation in the size of ingot that can be cast, and for producing a given rotor the forge master is careful to see that an ingot is used of sufficient size to give the necessary reduction of area. In producing a thoroughly satisfactory forging, the amount of the forging work that is to be done is important, but it must be borne in mind that soundness is not imparted by the forging process. The vital factor is that the ingot from which the forging is made must be sound in the first instance, and the soundness of the

ingot in turn is dependent on the care and skill with which the steel is made. It is for this reason that, in so whole-heartedly advocating the solid rotor, I nevertheless pointed out the danger of the construction unless the forging is obtained from a firm of high repute. Perfection with material of any kind is impossible, but it is certain that a forging that is produced and guaranteed by one of our large steel makers is as dependable as any material that can be obtained, and more dependable than most.

In his remarks concerning the unpierced-plate construction, Professor Stoney overlooks the high and indeterminate stresses in the screw threads of the bolts and the great weakness that results thereby.

In reply to Mr. Juhlin, the statement that the bursting stress in the solid rotor is always lower than the tooth stress, was based on an examination of actual designs —in no case that has yet arisen in my experience has the bursting stress been as great as the tooth stress. Obviously this is a matter of practice, since by making the slot shallower the tooth stress could be indefinitely reduced. With a 50,000-kw. machine at 1,500 r.p.m., the bursting stress is appreciably lower than the tooth stress. One can hardly agree with Mr. Juhlin's statement that the great pressure on the rotor end coils is a factor against displacement, since it is only on account of the pressure that the displacement is dangerous.

With regard to the number of rotor slots, the problem as to the best disposition of a given winding—to which reference was made in the paper—is somewhat different from the problem to which Mr. Juhlin refers of the maximum output that can be obtained from a given rotor. It is my opinion that displacement of the rotor end windings will more probably be brought about as a result of prolonged running than as a consequence of applying a short-circuit test to the machine. I disagree with Mr. Juhlin that the conditions are more severe when an alternator running unloaded and uncoupled to its turbine is short-circuited than may occur in service when the machine is running in parallel with plant of relatively great capacity. I have seen many short-circuit tests made on alternators running fully excited and driven by a motor, but in no case was there any great fall in speed, and the test under such conditions cannot impose any great mechanical duty on the rotor. I concur with Mr. Juhlin's opinion that a solid rotor of 57 inches diameter can be used for as large outputs at 1,500 r.p.m. as are at present being contemplated. The fan design to which Mr. Juhlin refers has been dealt with earlier in the reply, as also have his remarks concerning the specification that is given in the paper. Mr. Juhlin's contribution to the discussion is most interesting and valuable.

With reference to Mr. Kuyser's remarks, it should be pointed out that nickel-chrome steel is available having as high a tensile strength as 100 tons to the square inch, but it is doubtful if it is desirable to employ such material for end bells.

In writing the paper one of the objects was to endeavour to show the maximum diameter of rotor that it is *desirable* to employ; Mr. Kuyser is dealing with rather a different problem in showing the greatest rotor diameter that it is *possible* to employ.

I fully concur with Mr. Kuyser's views concerning the suitability of the solid rotor for single-phase work, as is mentioned earlier in the reply. The trouble with insufficient saturation—to which I refer in the paper —did not occur with machines of my design and I regret that I am not at liberty to give the additional information for which Mr. Kuyser asks.

Mr. Kuyser's remarks that material can be overstrained without the elastic limit being "ruined" is not at all clear. Once the material is given a permanent set, then by definition the elastic limit has been exceeded. In making his remarks on this subject, Mr. Kuyser is overlooking that local permanent deformation is the first stage in the process of fatigue failure, and further, that general deformation would almost certainly be accompanied by complete loss of balance if not by any worse happening. Materials must be worked within the elastic limit, and since, as explained in the paper, for different materials, the ratio of ultimate strength to elastic limit varies very considerably, it is clear that the former cannot be taken as a basis for computing permissible stress. The unpierced-plate rotor which failed—to which reference is made in the paper—was constructed in Germany in the early part of 1913 and was running in Italy at the time of failure. Mr. Kuyser's remarks are very interesting and informative.

DISCUSSION ON

"THE CONTROL OF LARGE AMOUNTS OF POWER" *

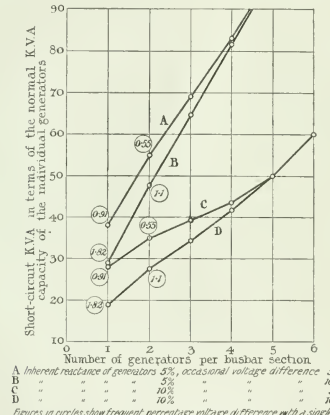
Newcastle Local Section, 8 April, 1918.

Mr. A. H. W. Marshall: The valuable quality which a large power system possesses of being able to stand up against heavy peak loads operates adversely when short-circuits occur, as the disturbance is correspondingly more widely spread. This disadvantage, however, can be, and is being, met by the proper use of impedance and discriminating protective gear. I have always held, and I am pleased to find myself in agreement with the author, that the right place to get reactive drop is between sections of the busbars, assuming that the feeders are long enough, as they should be, to prevent shunting where they are interconnected at outlying substations, and that the generators possess as much impedance as can be taken care of by hand or automatic regulation. That external reactance is necessary at all is proved by the breaking down of transformers and switchgear on short-circuit under heavy conditions. While the switches can probably be made sufficiently safe, it seems doubtful to me whether transformers can be so constructed. The transformer is, I think, the weakest item of the plant on a large power system and although improvement in design has made great strides during recent years, it has not kept pace with the conditions under which the transformers have to work. If we can transfer some of the heavy short-circuit stresses from the transformer to the more solidly built reactance so much the better. Adequate protection cannot of course be afforded by any form of automatic cut-out gear, as the mischief is done before any switch has time to operate. The author's analysis of the use of busbar reactance is of special value to anyone having to do with the design of a large system lay-out.

Mr. J. R. Beard: The paper is a complete reply to the criticism occasionally voiced from uninformed quarters that the technical developments of electric power supply are not keeping pace with the projected large developments, such as those foreshadowed in the report of the Coal Conservation Sub-Committee. I also wish to congratulate the author on dealing with the subject of reactances in a critical spirit with a recognition of their limitations. One so frequently sees the indiscriminate use of reactances urged as the cure for all evils that it is as well to bear in mind that in this district most satisfactory service has been given from a network with a maximum load of over 100,000 kw. without any help from such apparatus, although undoubtedly the system here has now reached the stage when the installation of reactances has to be seriously considered. In fact arrangements are now in hand for dealing with the busbar sectioning of the larger power stations on very much the lines suggested in this paper. The data which the author gives regarding the location of feeder reactances is interesting, but in general I think the use of reactances should be considered mainly from the point of view of safeguarding the main power-station switchgear. If this is satisfactorily done the ordinary inherent feeder and transformer reactance will usually be ample to protect the switchgear and apparatus on the system. An exception to this is the case of local supplies in the neighbourhood of the power stations, which should preferably be dealt with through local networks quite separate from the main distribution system, and I agree that on the feeders to such local networks reactances should be installed, particularly as the resultant voltage-drop is not in such cases of any importance. While in general agreement with the paper, there are several points which I should like to refer to in detail. On page 274 under the heading "Limitation of Voltage Disturbance" it is stated that "in the case of induction motors a heavy fall of voltage is not serious so long as the fault is cleared in about two seconds or less." This statement is only true if the low-voltage releases which are usually fitted are equipped with a delaying device. I have known many cases of annoying temporary interruptions due to the action of the instantaneous low-voltage releases caused by the momentary drop of voltage under fault conditions. The attention of manufacturers of motor control-gear should be specifically drawn to this point. The author presses very strongly the desirability of equipping each important circuit with duplicate oil switches (see Fig. 9). Our experience in this district does not bear out the author's recommendation, as any operating advantages which might have resulted from such duplication of oil switches would certainly not have justified the very heavy extra cost. No mention of the doubling effect was made in the paper. This effect is well known to exist in the case of alternator short-circuits, but it is not so generally realized that it also occurs with reactances and with ordinary static transformers. I had some difficulty in following Appendix II on the rating of reactances. While the method suggested may be useful for theoretical calculations it does not seem at all applicable to practice, where, for example, plant capacity varies from time to time and adjacent sections are not necessarily of the same capacity. I think it is desirable that a standard method of rating reactances should be adopted, and I would suggest the method which seems to prove easiest in practice, namely, to rate them on a k.v.a. basis, specifying in addition the system voltage and the percentage voltage drop at the full-load rating. While on the subject of rating, I think it should be clearly realized by prospective users of reactances that they have not the same overload capacity as a static transformer, since practically all the losses are proportional to the square of the current. Another point to bear in mind in connection with rating is that for the same ohmic value the k.v.a. capacity increases as the square of the current-carrying capacity, so that it becomes an expensive matter to provide large margins in carrying capacity. The part of the paper which inter-

* Paper by Mr. E. B. Wedmore (see p. 269).

ested me most was that dealing with busbar sectioning reactances and their calculation. I do not think the author is quite justified in dismissing the "ring" arrangement and recommending the general use of the "star" arrangement. For example, his statement that with the ring design 50 per cent greater reactance k.v.a. is required, is based on the assumption that it is necessary to guard against the ring being broken at the same time that two adjacent generators are out of commission. Such an exceptional emergency could be easily dealt with by switching, and does not in my opinion justify larger reactances. In any case, if one assumes such a probability, is it not even more justifiable to assume the probability with the star design of the tie bar being out of commission, which would of course throw the whole busbar arrangements out of gear? Given equality in the k.v.a. capacity



A Inherent reactance of generators 5%, occasional voltage difference 5%
B " " " " 5% " " " 10%
C " " " " 10% " " " 5%
D " " " " 10% " " " 10%

Figures in circles show frequent percentage voltage difference with a single machine out of commission. With more than two machines per section it is zero.

FIG. K.

general power factor of the system. This seems to be usually permissible, as it is general practice to specify generating plant for a slightly lower power factor than that of the system on which it is intended to work. In the particular case in question the generators were designed for 0·75 power factor, while the power factor of the system was slightly above 0·8. The problem was approached as being primarily one of balancing the minimum permissible short-circuit current against the maximum permissible voltage difference between busbar sections. As this investigation had reference to existing plant as well as to new plant, figures were prepared for generators having inherent reactances of both 5 and 10 per cent, the latter figure of course being that most nearly corresponding to modern practice. The quantity of spare plant at maximum load was assumed to be 20 per cent, i.e. the average load per section to be 0·8 of the capacity of the generators connected to the section. The worst emergency condition which need to be assumed in practice is when two

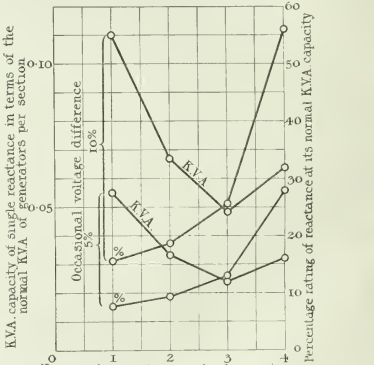

KVA capacity of single reactance in terms of the normal KVA of generators per section
Occasional voltage difference
10%
5%
K.V.A.
%
Number of generators per busbar section
Percentage rating of reactance at its normal KVA capacity

FIG. L.

of the reactances required for the two designs, the star design has two distinct disadvantages to set off against the fact that it is somewhat simpler from the operation point of view. These are:—(*a*) A short-circuit on the tie bar is fed into by all the sections in parallel. (*b*) An extra line of busbars is required. My present view is that the balance of advantage for a new station is in favour of the ring design, but I agree that for dealing with alterations and extensions to existing power-station busbars the star design may in many cases prove more convenient. As the paper deals principally with the calculation of busbar reactances for the star design it may be of interest if I give a few details of similar calculations for a ring design which I recently carried out in connection with a station of over 100,000 k.v.a. capacity. It was assumed that, as suggested by the author, load would be transferred from one section to another at a higher power factor than the adjacent generators are out of commission at the same time, the several generators on either side being available. This is quite an extreme condition, but is one for which it is desirable to legislate, provided it is borne in mind that a 10 per cent difference of voltage or even more is not a very serious matter on such rare occasions. A condition which will occur quite frequently is for a single generator to be out of commission. In such a case it is not in general desirable that the difference of voltage should exceed $2\frac{1}{2}$ per cent, and it should preferably be less than this. The curves in Fig. K herewith show how the maximum short-circuit current at any point of the busbars (in terms of the k.v.a. capacity of an individual generator) varies with varying numbers of generators per section for generators with 10 per cent and 5 per cent inherent reactance, and for arbitrary values of 5 per cent and 10 per cent for the permissible voltage difference between busbar

sections under the rare condition of two adjacent generators being out of commission at the same time. A further factor to be taken into consideration is the k.v.a. capacity

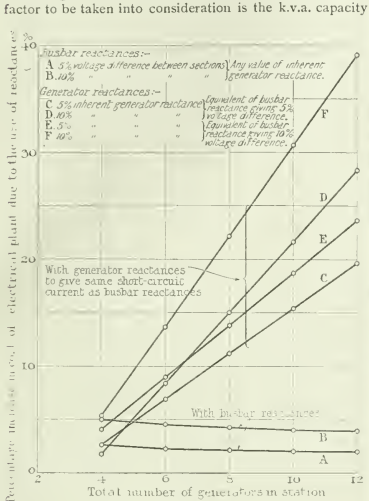

Busbar reactances:—
A 5% voltage difference between sections
B 10% " " " "
Any value of inherent generator reactance.
Generator reactances:—
C 5% inherent generator reactance
D 10% " " "
E 5% " " "
F 10% " " "
Equivalent of busbar reactance giving 5% voltage difference.
Equivalent of busbar reactance giving 10% voltage difference.
With generator reactances to give same short-circuit current as busbar reactances
With busbar reactances
Percentage increase of electrical plant due to the use of reactances
Total number of generators in station

FIG. M.

of the reactances corresponding to the curves in Fig. K. This is shown in Fig. L, and the same figure also shows the values of the reactances expressed in the usual way as short-circuit k.v.a. also increases, while the total k.v.a. capacity of the busbar reactances falls as the number of generators per section is increased to three, and then begins to increase again. Consequently the number of generators per section should never exceed three. One per section is rather extravagant in reactance capacity, and obviously should not be adopted unless the generators are so large that the switchgear would otherwise be severely taxed. While two generators per section require somewhat more reactance capacity than three, the relative reduction in the short-circuit k.v.a. is so marked that for general purposes it would appear to be the more desirable number to adopt. In order to compare the relative merits of busbar and generator reactances, Fig. M was prepared to show the relative capacities and costs of generator reactances designed to limit the short-circuit k.v.a. to the same values as would be attained with busbar reactances installed between sections with the suggested loading of two generators each. From Fig. L it will be seen that for a station with only four generators it is slightly more economical to use generator reactances, but that the extra cost of reactance is in any case so small that this is not important. If there were no possibility of the total number of generators exceeding four, the margin of advantage would probably be in favour of generator reactances. In practice it is usually impossible to set such a limitation, and since for larger numbers of machines the relative cost of generator reactances increases very quickly, it is in general desirable to adopt busbar reactances in all cases. Referring back to Fig. K it will be noticed that the reduction in short-circuit k.v.a. is not very marked if the size of busbar reactance is doubled so as to give an occasional voltage difference of 10 per cent instead of 5 per cent. In order to settle the influence of this the curves in Fig. N were calculated, from which it appears that there is not much point in busbar reactances giving an occasional voltage difference of more than 5 per cent, but that up to this point the short-circuit k.v.a. has been decreasing at a rapid rate. This holds for generators with

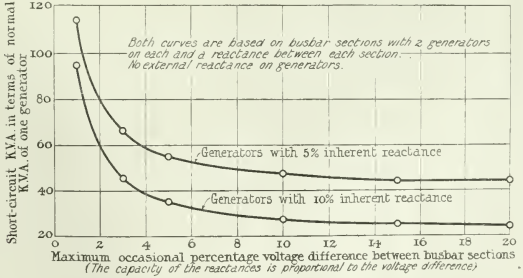

Both curves are based on busbar sections with 2 generators on each and a reactance between each section.—No external reactance on generators.
Generators with 5% inherent reactance
Generators with 10% inherent reactance
Short-circuit KVA. in terms of normal KVA. of one generator
Maximum occasional percentage voltage difference between busbar sections
(The capacity of the reactances is proportional to the voltage difference)

FIG. N.

the percentage voltage drop across them at their rated carrying capacity. From Figs. K and L it will be seen that as the number of generators per section increases, the an inherent reactance of either 5 per cent or 10 per cent, and the capacity of busbar reactance giving an occasional voltage difference of 5 per cent may therefore be decided

upon as the most suitable for general use. It is interesting to note from Fig. N that the increase in the inherent reactance of the generators has quite a large effect on the short-circuit k.v.a. This is shown more clearly by Fig. O in which the short-circuit k.v.a. is plotted against the inherent reactance of the generators on the same basis of two generators per section and on the assumption that the suggested capacity of busbar reactance is installed. It may, of course, be difficult to obtain such high values of inherent generator reactance under short-circuit conditions, and if so, the curve suggests that it may be advisable to supplement the busbar reactances by a certain amount of external reactance in the generator circuits. In this case the value of such generator reactance would be independent of the number of machines in the station. The

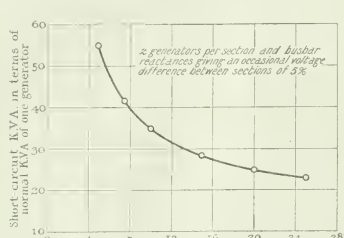


FIG. O.

foregoing investigation seems to indicate the following general conclusions:—

(1) There should preferably be two generators per section. This, I think, agrees with the author's own conclusions.
(2) The busbar reactances between each section should have a k.v.a. capacity about 1/15th that of the normal k.v.a. capacity of each generator, and a percentage rating of about 10 per cent at the normal k.v.a. output of the reactances.
(3) The total short-circuit reactance in the generator circuits should be at least 12½ per cent, and if this cannot all be dealt with by the inherent reactance of the generators, external reactance should be added to bring the total up to the required figure.

If these features are adopted the maximum short-circuit k.v.a. at any part of the busbars will not exceed 30 times the normal k.v.a. capacity of an individual generator. With 25,000-k.v.a. generators this gives 750,000 k.v.a., which is within the capacity of present-day power-station swichgear. With 50,000-k.v.a. generators this gives 1,500,000 k.v.a., which is probably within the capacity of switchgear that will be available in the immediate future. As far as voltage difference between sections is concerned, the suggested arrangements would frequently give ½ per cent difference, and on rare occasions 5 per cent.

Mr. R. M. Longman: I should like to refer to the question of using transformers as choking coils and reducing the impedance for normal operation by direct-current excitation. Has the author ever considered the use of iron reactances for earthing the neutral, using direct-current excitation—either employing the full choking effect normally and reducing it by applying direct current, or else introducing the choking effect by letting the direct current flow under normal conditions and reducing it as the fault develops. I notice the author has decided on 6,000 volts for the generator pressure; is that in his opinion the highest limit for this country? Why not double it? Has the author considered the case of a system with regulators—most large systems will require them—and would it not be possible to incorporate the reactance with the regulator? We want to reduce the number of pieces of apparatus as much as possible. On page 274 reference is made to the time required for clearing a fault, ½ second being mentioned. Can we take that as a standard figure? In regard to rotary converters, is there not a danger of these getting reversed on a bad short-circuit, such an occurrence being, of course, a rather awkward point? Regarding the question of reactance in busbars, usually we want to know how much current is passing through them, and that necessitates the use of instruments, which also means inserting current transformers in the busbars. I assume that a straight-through type would be used, which should be made as sound as any part of the busbar arrangement, but it is necessary also to insert both an indicating wattmeter and power-factor indicators. I assume the author would advocate the use of such instruments. In connection with Appendix I, has the author an empirical formula by which he can compare the value of switches? I suppose each manufacturer uses a formula of his own. In regard to the question of the number and arrangement of switches per generator and per section, I do not think it is necessary to have two switches for a generator. In my opinion the trouble one has experienced indicates that usually it is only necessary to clean up the sparking contacts or renew them. What seems to be required is a switch to short-circuit the reactance normally, and to open and insert the reactance in circuit immediately a fault develops. The point is: Can such a switch be made to operate quickly enough?

Mr. H. W. Clothier: There may be a need for the use of reactances on very large power schemes and when linking up old systems which include weak plant and switchgear, but the experience of this district has proved the possibility of running a large system (100,000 kw. of generating plant) on good "continuity of supply" principles without the use of reactances. Reactances are undesirable "passengers" on a system, as they absorb a certain amount of energy, cause endless difficulties in sectionalizing and in the general lay-out of the transmission network, and complicate the power-factor problem, tending to reduce the energy which can be transmitted by the mains. Moreover, it does not always follow that by reducing the short-circuit current to one-third, the stresses on the switchgear are reduced to those of a generating plant of only one-third the capacity, as suggested by the author. For instance, switches are sometimes selected to deal with, not the initial maximum short-circuit current, but the current at the instant of the separation of the sparking contacts after allowance has been made for the normal lag in the operation of the relay, trip coil, and switch mechanism. At this

point, owing to the effect of armature reactance in the generating plant, the reduction in the short-circuit current is not proportional to the increase in reactance of the circuit, i.e. the decrement of the current is slower in the case of the heavier plant with reactance, and therefore the current is greater at the point where the sparking contacts separate. Given switches operating in 0·15 to 0·2 of a second, this may make a very considerable difference to the stresses on the switches, owing to the steep gradient at and about this point, particularly as it happens to be that part of the curve where the assymmetry or "doubling" effect is still in evidence. Probably this objection to the use of reactances would disappear if switches were invariably selected to be capable of breaking at the maximum short-circuit current. Even then it is a matter for investigation to what extent the artificial increase in the impedance of the transmission network by the introduction of reactances affects the intensity of an arc on breaking short-circuits on various parts of the system, and it is to be hoped the Institution will shortly take this up. The author draws attention to the comparative ease in clearing faults to earth and the necessity of avoiding faults between phases, whereas he recommends a design of switch (Fig. 7) on which the exposure of conductors invites short-circuits between phases—the very fault he wishes to avoid. However good the clearances in air, unless, indeed, an impossible amount of room be taken up by the switchgear, there is always the risk of "open arcing" between exposed conductors. The author seems to admit that the practice on machine design is better because "throughout their length the conductors are covered . . . and separated by earthed metal parts." Why not be consistent in ideals and recommend that the conductors of switchgear should also be enclosed? The author's points about switches of "great mechanical strength" under Appendix I, in the first paragraph on page 279, seem to conflict. He says: "great mechanical strength is not justified in so far as it arises from unfortunate experiences with over-rated switches." Surely if the mechanical construction is the weak point, the best way to improve the rating is to increase the mechanical strength sufficiently. With this he would appear to agree as he continues—"the increase of mechanical strength is valuable where the normal service is easy but where one has to provide against an unlikely contingency." Most automatic switches are subject sooner or later to this "contingency," and when it does occur the switch must be strong enough to resist it. The fact that it has been possible to run this large system without the use of artificial reactances has been brought about by great attention to protective systems and to the mechanical strength of the switches used in the consumer's substation, and it is questionable whether it would have been possible with typical switches (Fig. 30) as represented in the paper; either the operation would have been too slow to maintain continuity of supply or, if speeded up to the required degree, the tanks and method of suspension would have had to be materially strengthened.

Professor W. M. Thornton: The author's analysis of the conditions under which reactances are effective is of the greatest interest to us in this district. There is only one point I should like to ask about. It seems to me that an arc begins to break when the total circuit voltage due to both the machine voltage and the total inductance is equal to that required to maintain a steady arc, and is falling faster than it at that point. If this be so, is there not a limit where the added reactance has more influence in maintaining an arc than the circuit gains by the limitation of the current? In the long-drawn-out arc of a high-voltage break in air it would not seem unreasonable to take the arc voltage to be proportional to its length, and an expression might be obtained for the critical reactance on this assumption. The whole position turns on the best compromise to be made between a switch breaking quickly after a fault on a large circuit and one breaking after many periods on a smaller one, having regard to the heavy mechanical forces in the system, which should be cut off as soon as possible, and the destructive action on the switch in its operation. If it is the system that one should think of most, the balance is in favour of rapid switching rather than holding on to the current by reactance.

Mr. V. O. Davis: On page 269 the author states that the size of a generating station may be doubled without excessive expenditure on switchgear. Most people are now in agreement with that from a general point of view. Many of us have, however, recently had experience in the extension of old generating stations in which the existing switchgear is by no means suited to cope with even a small increase of power, and such a condition somewhat complicates the problem. Fig. 1 shows two curves, A and B, of the decrement of short-circuit current in a typical generator. I have compared some records which I have of short circuits on large turbo-alternators with those shown in this paper, and I find that in most cases my curve is similar in shape but shows a rather longer time lag in coming back to normal. I would ask the author from what source he has obtained his curve and how he would expect the decrement of the short-circuit current to vary with different machines. On page 275 there is an apparent discrepancy; the author mentions a typical case of five busbar sections, generator reactance of 17 per cent and busbar reactance of 6 per cent where the maximum value of the short-circuit k.v.a. is kept down to three times the plant capacity. Using the formula given in connection with Fig. 6 I make it out to be twice instead of three times and I should like to ask for an explanation. The shape of the curves in Fig. 6 shows up clearly the fact that when the ratio of B/A is increased over and above about 0·4 to 0·6 very little extra result is obtained by adding large busbar reactances. Turning to Fig. 9, duplication of oil switches, about which a point has already been raised in the discussion, I should like to ask whether the author recommends that the non-automatic oil switches should be of smaller rupturing capacity than the automatic switches, or in other words should be regarded in the nature of oil-immersed isolating switches. I should also like to join issue with Mr. Beard regarding the "star" arrangement of reactances. I think the chief use of reactances in the near future will concern the modification or re-design of switchgear in existing generating stations in order to extend their capacity. Such alterations will have to be carried out without disturbing the existing switchgear, and the "star" design lends itself much more readily for work of this character than the ring arrangement, which involves more work on the busbars.

Mr. A. Collins: In the application of busbar reactances consideration must be given not only to the expenditure on individual pieces of apparatus on the system, but to the expenditure on the distribution system as a whole. Care must be taken that none of the advantages of a large interconnected system are sacrificed in order to keep down the cost of the switchgear installed on consumers' premises. The author would appear to have in mind for this purpose switchgear of much smaller breaking capacity than that which has already been standardized on several large systems in this country. Such practice would, of course, necessitate more extensive use of artificial reactance than has hitherto been found necessary. The addition of artificial reactance in feeders could only be justified under exceptional circumstances, but on large systems I think the use of single-core cables is worthy of consideration, at least for all feeders near to the generating station. In addition to increasing the inherent reactance, this would provide an earthed metal barrier between phases on the feeders, and a short-circuit on a cable, or what is more likely in a dividing box, would be impossible. As opposed to the author I do not favour the air-insulated reactance, which has many disadvantages from the point of view of accommodation as compared with the iron-clad type. As to reliability, an oil-immersed iron-clad reactance coil is a more simple piece of apparatus than the step-up transformers in which the additional generator reactance is usually embodied, and there should be no difficulty in obtaining a suitable factor of safety.

Mr. A. W. Crompton: In Fig. 9, alternative proposals are given for arrangements of oil switches and isolating switches. In regard to the circuit with two non-automatic switches, is the author of the opinion that it is sufficient to have these switches open without the addition of any air-break switches when it is required to work on the automatic oil switch, whatever the voltage of the circuit and also when it is possible to make the circuit alive from the other end? Many people are not satisfied that apparatus is safe to work upon unless the actual break in the circuit can be seen. Referring to the formula on page 283, is there any definite reason for writing it in this form? It can be simplified to $f = (B/A + 1) \div (NB/A + 1)$. I should also like to know if an approximate formula has been used in calculating the short-circuit factor for the closed-ring design, as the actual formula must be somewhat complex.

Mr. E. B. Wedmore (*in reply*): Mr. Beard has made an independent investigation into the problems arising in the employment of busbar reactances, and we are in close agreement in the conclusions reached. I note that he assumes a higher limit for the difference of busbar voltage on adjacent busbars than I have allowed for. This of course admits the use of more reactance, but does not give much more protection. For example, with generators having 12½ per cent reactance an increase of busbar reactance from, say, my figure of 7·2 per cent to 2½ times this figure, with 4 sections, only reduces the short-circuit currents in the ratio of 4 : 3, whilst the busbar voltage difference has been increased in the ratio of 2½ : 1. Mr. Beard suggests generator reactance of 12½ per cent, and his concluding figure of 30 times the rated capacity of one generator really corresponds closely to my figures, because with the star design with two generators per section I have scheduled 7½ per cent reactance, and this gives with 4 and 5 sections and 20 per cent spares, 24½ and 27 times respectively the rated capacity of one generator.

On the subject of permissible busbar voltage variation it is interesting to compare Mr. Beard's views with the remarks of Captain Taylor in the London discussion (page 292).

I do not quite agree with Mr. Beard's proposed system of rating individual reactances because it leaves the current-carrying capacity to be calculated, and the derivation of this from the k.v.a. rating and percentage drop is not immediately obvious. The addition of a k.v.a. rating is good, as it gives a measure of the size. The percentage reactance rating may be misleading. I think therefore it is better to adhere to amperes carrying capacity and ohms at a given frequency. From these a percentage rating can be deduced on any desired basis. In dealing with impedances on a given installation it is convenient to reduce all the resistances and reactances to a percentage basis, choosing any convenient figure for the kilovolt-amperes, such as 10,000 (or 100,000). If then the impedances on any circuit add up vectorially to x per cent the maximum short-circuit current becomes 10,000 (or 100,000) $\times 100/x$.

As between the star and ring systems, there is so much to be put on both sides of the balance that it can be made to turn towards either side. I would only add two comments. The first is, the tie busbar has a much larger factor of safety even than the main busbars, bearing in mind that everything on the busbar side of the switches is part of the busbar from the standpoint of possible trouble, and that there are no automatic switches on the tie busbar. The other is that whilst in dealing with cases which have arisen I have always found it *possible* to make a satisfactory compromise with the ring busbar, it has always been *easy* to do so with the ring design.

In reply to Mr. Longman, I do not advocate the use of reactance in the neutral connection, and have given reasons in the discussion at Bristol. Automatic reactances might be used to limit heating effects, but they have not been made to operate sufficiently rapidly to limit the maximum mechanical stresses and instantaneous potential disturbances. The figure ⅓ second is taken as typical of modern switchgear, but there are many switches operating more quickly than this.

Mr. Clothier bases his opening remarks upon experience in this district. The development of electric distribution in this district is unique in several respects. I do not think we shall find a close parallel in prospective developments anywhere else in this country. There is much to be learned from the experience gained here, but it is necessary to recognize the differences in the problem as it presents itself in other districts. Broadly speaking, the tendency in districts such as Glasgow, Manchester, Sheffield, and Birmingham seems to be towards greater concentration of power in a given area and more direct supply. That is, we do not get the same protection from transformer and feeder impedance. Future developments in the

large towns in this district also will lead to greater localized concentration of power, and it is likely that the use of artificial reactances will be found increasingly necessary.

Referring to the effect of time lag, the curves in Fig. 1 bring out the point to which Mr. Clothier alludes, but the discrepancy is small Taking figures now available * for typical machines, including an allowance for doubling effect, and allowing $\frac{1}{2}$ second for the switches, I find the short-circuits with 10 per cent and $33\frac{1}{3}$ per cent reactances are in the ratio of 2·7 : 1. This is practically 3 : 1, my approximate figure. Mr. Clothier's argument re insulation of conductors will not bear examination. The one feature which keeps machine designers awake at nights is insulation. Why don't they follow the other construction and use air insulation throughout? We cannot compare different kinds of apparatus in this way. Again, Mr. Clothier's version of my argument leaves out the essential item, that the insulated conductor should be in intimate contact with the earthed metal, so that on a fault occurring the breakdown is localized. A breakdown on such a conductor is like a cable fault, whereas a breakdown on compounded ironclad switchgear is like a cable-box fault, and is liable to take the form of an explosion.

On the subject of mechanical strength of oil switches I agree with Mr. Clothier in the main, but the diagnosis of the cause of trouble has not always been correct. If a switch explodes, the practical man says make it stronger—but attention to other details might have prevented the development of explosive forces. I know of such cases. The problem of providing adequate substation switchgear in this district has been simplified by the large inherent impedance to be found in most parts of the system. From the standpoint of my paper the oil switches used here are of the type illustrated in Fig. 30, and are in fact developments from the same original model.

* E. M. Hewlett, J. M. Mahoney, and G. A. Burnham: "Rating and selection of oil circuit breakers," *Proceedings of the American Institute of Electrical Engineers*, 1918, vol. 37, p. 41.

Professor Thornton's hypotheses as to the action in oil switches are not sufficiently complete to admit of deductions. On severe short-circuits practically all the impedance is reactance. The current approaches a lag of 90°. For a considerable margin below 90° the potential is substantially a maximum in the neighbourhood of zero current.

I would refer Mr. Davis to my replies in London and Manchester for references to Fig. 1. There is no discrepancy in the case cited by Mr. Davis. I have used more than one short-circuit factor in the calculations. In Figs. 6, 15, and 16 the factors give relative values, as shown by the context. In Figs. 18, 19, and 20 and Schedule C the factors give absolute values. In the case cited, with the star design, and generator and busbar reactances of 17 and 6 per cent respectively, the formula on page 283 and Fig. 6, show a factor of 0·5, i.e. the short-circuit current with busbar reactance will be one-half what it would be without busbar reactance. This ratio of 2 : 1 is a relative result. Now with 17 per cent generator reactance and no busbar reactance the short-circuit current would be 6 times the rated current, so with busbar reactance this figure will be 3 times. This is an absolute value.

In reply to Mr. Crompton, oil-break isolating and selector switches are in use, and can be designed so that they are at least as safe as air-break switches, if not more so. I know of no simplified formula for the short-circuit factors with closed ring busbar reactances.

In reply to Mr. Collins, in cases where large short-circuit currents have to be dealt with, one may have to employ on small circuits apparatus primarily designed for larger stations, but one cannot contemplate furnishing large numbers of small consumers with heavy substation switchgear. The figures I have given are typical of general practice, and are based on designs known to have conservative ratings. It will be to common advantage when fancy ratings are eliminated from switchgear propositions.

Scottish Local Section, 9 April, 1918.

Mr. J. K. Stothert: On page 270 the author speaks of very large stations up to 200,000 k.v.a. In the near future such large stations will be the very nerve-centres of all our industries, and I think it is obvious that any future war will be fought out even more in the air than the present struggle has been. It will be easy therefore if we build very large power stations (unless they are put in dug-outs) for the enemy to destroy the immediate activities of industries over a very large area. It was hinted, I think, in London recently, when this question was under consideration, that it might be advisable in view of such a possibility to have more than one power station to each large industrial area. I should like to hear what the author has to say on this matter. There is a point with regard to overhead lines and underground cables. It is the custom in this country to bury our cables underground, but anybody who travels abroad is aware that overhead lines are much more largely used and, I am told, with very little difficulty and at much less expense. I think the idea of the Coal Conservation Sub-Committee is to have throughout certain districts very large mains into which waste power would be fed and upon which industrial concerns would draw. It seems to me that the capital expenditure involved if a large proportion of such mains were underground would be enormous.

Mr. W. W. Lackie: The author advocates the use of two 100,000-kw. stations instead of one 200,000-kw. station. In Glasgow we have an area large enough to warrant the erection of a station of over 200,000 kw. on one site. I am glad the author agrees that it is better to put the reactance into a generator than to have it external. From Fig. 1 it will be seen that the switch which does not operate too quickly, i.e. in about half a second, has very much less energy to interrupt than the switch which operates in a quarter

of a second. Later in the paper the author indicates the need for a switch to operate in one-fifth of a second in order to obviate the shutting down of rotary converters. One would have liked to hear more about the improvement of power factor, but that has more to do with the running of generating stations than with their control. There is a very interesting statement about the minimizing of a fault due to a cracked insulator if the insulator is mounted in brick or stone with the supporting walls reinforced. The author says that the first indication of a fault is the occurrence of a dead short-circuit to earth. This is not in accordance with my experience. I have one fault in view where the cable was switched out of circuit before the lead on the earth side was damaged on a 6,600-volt circuit. In Appendix I the author does not think that the present demand for switches of great mechanical strength is justified, but I think he will agree that there is justification in the request for much stronger tanks for containing the oil surrounding the switches. There have been numerous instances of the tanks bursting as a result of shock when the switch was opened on considerable overload. The rupturing capacity of a switch is rather a vague term. It is stated that there are on the market to-day switches capable of rupturing 750,000 kw., and we are promised switches having double this capacity. Some time ago we were promised a reactance which would contain iron. This had a short-circuited secondary winding which on load was released and so increased the reactance of the primary. Nothing appears to have come of this, but the idea appears to me to be a good one. The arrangement of switchgear shown in Fig. 8 is typically American; British practice is somewhat different. The arrangement shows duplicate oil switches in conjunction with the isolating or selector switches. British practice is to have duplicate isolating or selector switches but on a single oil switch. I am of the opinion that it is better to spend the money on one good oil switch than on two inferior switches. The arrangement further introduces an enormous number of insulators. I think it is generally admitted that the principal source of trouble on high-tension switchgear has been due to cracked insulators, and if we can reduce the number of these to a minimum or avoid them altogether it is a step in the right direction. In the arrangement shown in the paper there will be not less than 600 insulators, whereas with standard British practice the number would be about 200. The author recommends that oil switches should be used for all normal switching, and that air-break switches should be used only for isolating parts already made dead by oil switches. I think he is aware that switchgear is obtainable which does not necessitate the use of isolating switches. I refer to the "carriage" type of switch of which Messrs. Reyrolle are the pioneers; and for our Dalmarnock works I have adopted an oil-immersed isolating switch. Our endeavour there is to enclose the conductors throughout their entire length from machine to consumer in insulating material protected by lead or iron, and the busbars will be run in solid. At present we are arranging to install reactance coils between two sets of busbars at Port Dundas electricity works. The recent addition to isolating switches, viz. the locking of these in, is not quite necessary. I know of a case where a main switch failed to operate, and the isolating switches, due to the forces in the conductor carrying the current, opened the circuit without any very serious mishap. The figures given at the end of the table of current densities and rise in temperature are extremely interesting and show the necessity of having protective gear on all high-tension systems. We had a large number of small current transformers on our system which I was informed would burn up in less than a second, but these are now practically eliminated. I should like the author to give us further information on the earthing of the neutral point of a three-phase generator or transformer. In the past we have earthed these through a resistance of large current-carrying capacity, but this is becoming a very cumbersome and costly piece of apparatus. Can he throw any light on the proposal to earth through a reactance?

Mr. N. C. Bridge: I believe that, generally speaking, the model station of the near future will have to deal with one or both of two distinct sets of conditions, presenting somewhat different features in the power-controlling arrangements by means of impedance. One type of station will deal with large demands concentrated within a limited radius, and will distribute at the generator voltage, say, 6,000 or 10,000 volts. The distribution system will be consolidated by interlinking the feeders, so that if the busbars are sectioned through reactances the feeders will also require reactance. The other type of station will deal with a number of more remote centres of demand and will distribute to these at 20,000 or 30,000 volts. The only interlinking in this case will be at the far end of each set of transmission lines through reactance between sections of the substation busbars. I think it is clearly established that generator reactance is more advantageous than any other form in limiting the short-circuit current; and this in the case of the first type of station would be provided by inherent machine reactance plus external coils in series, and in the case of the second station by inherent reactance plus transformer reactance between the machine and busbars. I agree with the conclusion on page 276 that the ideal number of machines per section is two. Were a single larger unit to be substituted as the author suggests, it would appear that there is no means of supplying magnetizing current to the section if that machine is out of service, except through the busbar reactances. I also agree that the ideal size of unit for some time to come will be 20,000 to 30,000 k.v.a. I do not agree, however, with the multiplication of sections, and I see very little justification for the author's rather extensive treatment in Appendixes IV and V of large numbers of sections or of machines per section. I regard the ideal number of sections as two only, for many reasons. This of course limits the plant capacity of the ideal station I have been speaking about to something in the neighbourhood of 100,000 k.v.a., but I consider this to be ample for any single switch-house to have to deal with. It might, however, be advantageous in some cases to erect a distributing and a transmitting station on a single site with eight similar generators, but with two switch-

houses. These would be paralleled through transformers to get interchange of power within reasonable limits. If the whole output of the double station were required at a common voltage, the two switch-houses would be paralleled through reactances. Now, if developments can be guided on these general lines, and if we are content with a moderate short-circuit factor, the problems of proportioning impedance seem to be fairly simple. With two busbar sections only in any one switch-house no question arises as to the relative merits of star and ring arrangements of busbar reactance, and when it comes to two coupled switch-houses a closed ring is obtainable without utilizing the auxiliary bars. This eliminates the principal objection to the usual ring arrangement. Fig. P illustrates my idea of the ideal 200,000-k.v.a. double station, and it will be seen that simplicity of control is one of the main features. I do not think that any one will care very much for the third busbar of the star system favoured by the author. It will present no little difficulty in accommodation, and adds another straw to the station engineer's burden of responsibility. Regarding the question of switchgear, in the author's model diagram

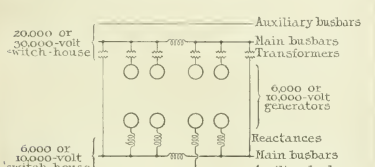


FIG. P.

(Fig 8) we have practically 50 per cent of idle oil switches, and I do not think this would show much confidence in the suitability of the switch for its work. It would appear, too, that the use of automatic oil selectors rather complicates the wiring arrangements for the balanced protective gear of the generator or feeder. I should like to ask the author what is the arrangement proposed for making the gear operative only on the particular switch in use on any circuit. I would also suggest that the oil switch in series with the busbar reactance in Fig. 13 is unnecessary unless the isolation of the section is a frequent requirement. With an isolator on each side of the reactance it can be withdrawn or inserted at any time when the short-circuiting oil switch is closed. On page 278 a point is raised by the author which I think deserves more emphasis, on the principle that prevention is better than cure. I refer to phase faults. There are two weak points in this respect in most of our existing distribution systems, viz. cable joints and substation switches. If cable joints are made with an earthed shield between phases, and if all single-tank three-pole oil switches working at the main voltage are replaced by single-pole switches with barriers as in the power station, the chances of phase faults outside the station should, I think, be considerably reduced. Finally, I do not consider an increase in the number of machines in a station to be a justification for an increase in the number of spares, as the more machines there are the less the overloading on the balance if one or two are out of service. I think the directors of any power company would get rather a shock if they were called upon to provide the capital for two units of the largest size merely as spares, as the author suggests on page 270.

Mr. R. B. Mitchell: So far as the application of reactances to distribution systems is concerned I agree with the author that their use is unnecessary. The development of selective protective devices has made this possible. Our experience in Glasgow with protective devices has been good and is becoming better and better as time goes on. The only weak point about them is that occasionally not only the faulty section is cut out but a healthy section or sections as well. So far as the protection of the generators is concerned (which after all is the first consideration) these protective devices have fulfilled their part. The cables forming the distributing system, as manufactured and laid at the present day, form, I think, the most robust and dependable part of the whole equipment, and not much trouble is to be expected from the cables in working. The same cannot be said of the various types of apparatus connected to the system, such as transformers, rotary converters, switchgear, etc.; but here again the protective devices come in and protect the generators from damage. The author states that as a safeguard it is necessary to divide the distributing systems into sections independent of each other. I agree that at the present time it is so; but is it too much to hope that in the future protective devices will become so perfected and so instantaneous and certain in their action that the whole system may be bound up solidly and so obtain the full capacity of the copper? In a number of supply systems at the present time, especially where new stations are being built, higher voltages are being adopted. That is to say, a pressure of 20,000 to 30,000 volts will be used to feed into the existing lower voltage system through step-down transformers, and the question arises whether the two voltages shall be perpetuated, or whether it is the correct policy to prepare for the gradual elimination of the lower voltage supply. Some people who take long views are prepared to advocate that policy, but if it be carried out it could only be carried out at enormous expense. After all, the lower voltage not only enables the supply authority to take on small consumers of, say, 100 kw. or under at a moderate outlay for switchgear, etc.; but if we continue to look on the higher voltage cables as feeders and the lower as the distribution system, the generators are protected on account of the impedance of the step-up and step-down transformers, and the 20,000-volt cables, from anything which may happen on the lower voltage network, where it is only reasonable to expect the great majority of faults would occur, although perhaps not the most serious faults. The double transformation is admittedly a disadvantage, and for the sake of simplicity it might be well to go in altogether for the

higher voltage throughout. Also the cheapening of the outfit required for the smaller consumers might be brought about by the introduction of a satisfactory 20,000 or 30,000-volt fuse which might be installed in these cases at a very much smaller cost than is necessary at present. Fig. 8 is a diagram of a switchboard with all switches in duplicate. Is it necessary to incur the considerable expenditure for buildings and switchgear which would be involved in order to obtain this duplication? The modern-type switch for 20,000 or 30,000 volts is very expensive, and the additional cost for buildings might amount to £10,000. I think that if the switches on a board are all of one size, and apparatus such as a crane be provided for their ready removal, one complete switch kept as a spare would fulfil the same purpose at a very much smaller cost. The type of reactance shown in Fig. 26 is being adopted for busbar sectionalizing in one of the Glasgow stations. Its advantages seem to be that it is of very robust construction, compact, and not so heavy as other types, such as that in which the conductors are built up on racks surrounded with earthenware. This latter type we are also about to install in another station, and comparison will then be possible between the two types. To my mind the only disadvantage of the type shown in Fig. 26 is that it is not flexible like the other type, and that if the would-be user is uncertain as to how much reactance is required he will be in a difficulty should he find after purchase that it has to be varied. The author suggests that switchgear of comparatively small rupturing capacity may continue to be utilized on large systems if protective devices in the form of time-limit relays are provided on circuits as a second line of defence in addition to the usual balanced protective gear. I should like to ask if in the author's opinion a time-limit relay has ever been evolved which will satisfactorily fulfil the purpose for which it was designed.

Mr. F. H. Whysall: The paper deals with a subject which we shall have to consider very seriously in the near future. The subject came under my observation some years ago, and it was decided that the most important thing to protect was the generator. I can, however, imagine circumstances under which the arrangements described by the author would be necessary. It is very largely a question of circumstance, and each case should be decided on its merits. I was impressed by what Mr. Mitchell said about protection. I agree with him that in the near future we shall have such perfect protection that we shall feel almost independent of anything but reactances for generator protection. Mr. Lackie referred to the difference between British and American practice. Like Mr. Lackie, I prefer British practice, which is to put in substantial switchgear, and I have never before heard of any one in this country contemplating the use of duplicate oil switches.

Mr. D. M. Macleod: The author recommends that two of the largest sized units be kept as spares. This, I fear, would not be justified, as the capital expenditure involved would be enormous. The usual practice is to install spare plant equal in capacity to the largest unit, and I think that this is found to meet all ordinary requirements. On page 270 the author refers to machines generating at 6,000 volts and to the pressure being raised to 20,000 or 30,000 volts for transmission, and he also refers to the switching being carried out on the high-pressure side. I do not see why the control should not be carried out on the low-pressure side—i.e. on the side least liable to disturbance. The question of overhead line construction has been mentioned. The author seems to think that we should continue to use overhead line transmission for small amounts of power and employ underground cable for larger amounts. I quite agree with the latter recommendation, but I think that when we come to deal with super stations overhead lines are quite inadmissible, because of their liability to be maliciously tampered with during industrial disputes and to fail due to stress of weather. The position as to overhead construction has undergone a very marked change since the beginning of the war, owing to the high cost of overhead line material. I do not think we can look for any improvement in this respect until some time after the war, and that, I think, should go a long way in helping engineers to decide as to the use or otherwise of overhead transmission; for it must not be forgotten that the chief justification for overhead construction lay in the fact that overhead work could be built at about one half of the cost of underground cables of the same current-carrying capacity. On the other hand, overhead lines involve high maintenance charges.

Mr. W. B. Hird: Regarding the very great complexity of the accessories installed in the search for safety from interruption of supply, mention is made in the paper of oil switches installed in duplicate and then further protected by special switches to cut them out in case of failure. Then it is proposed to add reactances in various parts of the circuit as a further protection. When it is considered that each new piece of apparatus installed is itself a possible cause of failure, it scarcely seems possible that the right line of development for ensuring safety should lie in such a duplication of auxiliary apparatus as is now being discussed. I am glad to gather from Mr. Mitchell's remarks that in the opinion of some of our central station engineers there is hope that a different line of development may be found to ensure the necessary safety. In this connection I am glad to see that the author favours the introduction of the reactance in the generators and cables themselves whenever possible, instead of installing a separate piece of apparatus, although from the point of view of the designer I should anticipate some difficulty in carrying out designs so as to obtain that ratio of reactances which will give the best protection. In connection with the use of reactances, after reading the paper I referred to discussions which took place at the Institution about 1892 in which Messrs. Mordey, Kapp, and Forbes, amongst others, took part. There was no question of "reactances" in those days, but the question was whether "self-induction" should or should not be introduced in alternator armatures; and it is very interesting to see how, in spite of the fact that our point of view is so entirely different, and our present knowledge of such a different order, much the same conclusions were then arrived at as are put before us now. If I may venture

on a small criticism, I think it unfortunate that throughout the paper reactance should be dealt with as a percentage drop. Whilst this is no doubt convenient for the purpose, there is too great a tendency for each section of the profession to adopt new definitions, new units, and a new nomenclature. This necessarily leads to confusion, and more especially in such cases as this when the word "reactance" is already established with a well-defined meaning, and represented by a definite mathematical expression. It is rather trying to have to learn a new language before one is able to follow a paper in a section of the industry with which one is not very familiar; and without any risk of being called pedantic one can, I think, object to such expressions as "the ohmic resistance of a reactance."

Mr. J. R. Cowie (*communicated*): The subject of the paper is one on which the attention of all engineers in large power companies and corporations is at present engaged. I think all engineers will agree that the combination of switchgear with reactance is and will be necessary, but in many of the suggestions put forward the author seems to advocate reactances as a means to the employment of altogether inadequate switchgear. When handling large amounts of power, 20,000-k.v.a. rupturing capacity is not permissible even on 440-volt work. Too little attention has in the past been paid to switchgear, and many engineers have bought in the cheapest market without much consideration being given to the forces which these switches require to control under fault conditions. Manufacturers are also to blame in that they have not marketed suitable material, especially for substation work. Figs. 2 and 3 are interesting as a means of utilizing the inherent reactance of feeder cables, but it is not at all clear at what point the author proposes to install switchgear—presumably, at the busbars at source. In which case on a 6,500-volt circuit this means switching out 8,000 kw. in the event of a fault on any one distributor cable, and if on 20,000-volt work 25,000 kw. The primary purpose of switchgear is to get rid of a fault without shutting down consumers. Each of the busbar cables at the distribution end ought to be controlled by a switch and protective gear. Switchgear capable of taking care of large amounts of power with a combination of busbar reactances costs thousands of pounds less than a combination of less sturdy apparatus plus busbar reactances and feeder reactances; and the cutting out of all surplus material results in the saving of thousands of pounds on the buildings. The point which the designers ought to keep before them is absolute simplicity of operation and getting the maximum work out of the available copper in the existing network. Limitations of the coupling-in on the network due to studying the position of reactance should be avoided. On page 274 the author is too modest in his assumptions of what substation gear can do. Such material is on the market with very conservative rupturing capacities from 50,000 k.v.a. to 350,000 k.v.a. This would appear to be realized, because one of the most important parts of the paper is on page 274, and reads as follows: "In new large power stations it is wise to provide space for the possible addition of feeder reactance." It is recognized that feeders which are very short before they reach their load centre will in all probability require to have this feeder reactance put in; but, wherever possible, feeder reactance ought to be omitted altogether. On the same page, I do not agree that any switch should be allowed two seconds to operate. The author, I think, means that from the machine characteristics this time might be allowed. The two seconds' time limitation is what is commonly known as the delaying action advocated in America and on the Continent, and means, on a mixed plant, the operation of reverse-current relays on the direct-current supply and disturbance to supply. These disturbances will not be tolerated by the British consumer. Apparently the author realizes this, because again on page 274 he says: "There is no doubt that the conditions are further greatly improved by the employment of quick-acting switchgear able to clear a fault in one-fifth of a second or less." That is on the fifth period at 25 frequency. On a mixed plant this figure should be the third period. In any case either of these figures calls for material much stronger mechanically than is now generally manufactured, and I immediately join issue with the author when he says that increasing the strength, while it increases the power of the switch to withstand heavy stresses, contributes nothing towards reducing burning. Increasing the strength does not mean the external portions only. The design of sparking contacts is one of the weakest parts in switchgear, whether on 20,000-volt work or for 440-volt work, and I am convinced that more switch failures have occurred due to these arcing fingers burning together and not allowing the oil switches to clear the fault, than in actual failure of the switch itself. The question of the design of arcing fingers is one which would repay investigation by a Research Committee of the Engineering Standards Committee. The conditions requiring investigation are behaviour under short-circuit and behaviour if the switch be closed on a fault. Gas production is not quite such a serious matter, and calls only for the introduction of suitable vent tubes and head of oil. Some of the older switches which we have on the Glasgow system are more reliable than apparatus which is more modern in design, and their reliability is purely due to robust mechanical construction. We are starting a new line of business in super-power stations, and Continental and American practice and information is at our disposal. The disturbances on these systems due to switches and reactances failing under short-circuit conditions are well known, and generally result in rebuilding the switch and reactances. Switch failures such as these will not be tolerated by the consumers in this country, and consequently by British engineers. We should design new apparatus to meet the new conditions, and not slavishly copy American methods as is advocated in the beginning of the paper. The author recognizes this, because from page 280 onwards varying arrangements employing internal and busbar reactances are described, but I think he requires to go further and design new switchgear. On page 280 surely the author does not mean that it is necessary to put in the duplicate switches shown on the diagram. Each one of these switches will cost some £2,000 to £3,000, and it would be far better to carry one spare

of each size and to put a portion of the money into material having greater mechanical strength. As a matter of fact, as already pointed out, this material with greater mechanical strength costs less than the present system advocated. There are further expensive details in design, and many thousands of pounds will be saved by the elimination of all surplus material. Fig. 13 shows the arrangement in use at present for most stations, and from the operating point of view it is a simpler design. The author, however, makes out a good theoretical case for the use of reactance in the star design (Fig. 12), but I think responsible engineers would be well advised to pay a little more for bigger reactances and aim at simplicity of operation. On page 274 the author talks about substation gear having a capacity of 20,000 k.v.a. No such gear is permissible on 6,600-volt or 20,000-volt work. Gear having a rated capacity of 50,000 to 350,000 k.v.a. is available and is more than ample to meet the requirements which are contemplated for many years to come. The cost of this k.v.a. rupturing capacity is given as proportional to the size. From 50,000 to 100,000 k.v.a. it is nearly this figure, but from 50,000 to 350,000 k.v.a. the increase in capacity is 7 times and the price 4 times. The form of isolating switch shown on page 290 with a so-called safety clip is a delusion and a snare and should be abolished. The other type of apparatus (Fig. 3) is more suitable for large power work. Recent experiences on the Glasgow system have shown that these switches can be blown open and form a serious menace to any men who may be working in the switch-house. I am in agreement with the author when he says that this type of apparatus should be enclosed in an oil-filled tank. On page 291 the author has gone into the question of the heating effects of large currents, and this is very valuable information. He has also considered on page 289 the question of the heating of conductors, the stresses on conductors, and the forces which take place in wattmeter-type transformers under short-circuit conditions. Wattmeter-type transformers should be abolished wherever possible, and the amount of high-tension metering on any system reduced to a minimum. The author points to the primary section which is used—on the current transformer 0·15 square inch. He may be interested to know that the section of copper in series transformers in substation gear in this city is 0·35 sq. inch, and for 20,000-volt gear 0·25 sq. inch. In any case, if the heating effects are calculated out for the size of 0·15 sq. inch, it will be found that in less than one second this copper will be vaporized. This question of copper section must be taken into account on the reactances.

Mr. E. B. Wedmore (*in reply*): Mr. Stothert's question lies a little outside the scope of the paper. By the time peace comes it is to be hoped that all peoples will have learned the truth of the nature of war so effectively that any repetition of it between civilized nations will become impossible. Failing this, I believe that the idea of putting generating stations in dug-outs does not nearly express the extent and depth of the slavery to the demands of the military system under which we shall be compelled to live in order to be ready for the next war.

The subject of the strength of oil switches has been dealt with in the discussion at Newcastle.

I do not quite follow Mr. Lackie in his comparison of what he describes as standard British practice with that which I have advocated. The use of carriage-type switchgear in large generating stations is not even common practice amongst British engineers, much less "standard." Carriage-type oil switches are generally provided with isolating switches, each requiring just the same number of insulators as those shown in the paper. Mr. Lackie's experience has been that the principal source of trouble in high-tension switchgear has been cracked insulators. The problem of successfully designing and manufacturing a plain solid insulator, such as is almost universally employed in large stations to support plain copper conductors and fittings in brick or stone cells, is a simple matter as compared with the problems arising with ironclad carriage-type switchgear in all its details in large capacities for high voltages.

References have been made to American and Continental practice. I agree that experience with many continental designs on large plants has been unsatisfactory. The designers have given too much attention to theory and too little to experiment and experience. The same does not apply to American practice. For many years the large plants in America have considerably exceeded in size corresponding plants in this country, and a great deal of valuable experience is available for our guidance.

On the duplication of oil switches, if we allow that oil-break switches should be used for all normal switching operations, then on average present-day installations the arrangement of two main switches per circuit will cost little more than that of one main switch with two oil-break isolating switches. On the largest plants duplicate main oil switches will cost more but will lead to the simplest arrangement from the operator's standpoint. As a percentage on the cost of the machine or feeder the item is very small. It is only the oil switch and its cell that has to be duplicated. The suggestion does not arise from any doubt as to the qualities of oil switches. Large oil switches are not so much better than other elaborate pieces of mechanism that they require no attention and give no trouble. Where, however, new constructions and experimental apparatus is being installed the suggestion should be viewed from the other standpoint as well. No expenditure of money will buy better than the best, or eliminate the law of probabilities.

Mr. Lackie cites the case of a cable fault in which the lead was not damaged. I have met such an example before, and it was found that the insulating material was sufficiently carbonized to form a dead short-circuit offering a negligible resistance, and thus preventing generation of excessive local heating.

The reactances employed in series with generators and feeders would pass many times full-load current at full voltage. The resistance in series with the neutral point of a machine will pass only a fraction of full-load current at full voltage, and thus has many times the ohmic value of the reactances referred to. Reactances having a similar ohmic value and current-carrying capacity may cost less, but owing to their

high ohmic value there is risk of resonance phenomena, especially at frequencies above normal, and the currents in the neutral are commonly of a frequency above normal. For this reason it is recommended that resistances and not reactances should be employed for earthing the neutral.

Where there is only one machine per section, Mr. Bridge anticipates trouble in the transfer of magnetizing current through the busbar reactance. Where, however, a section has no running machine on it, it should be coupled solidly to an adjacent section. This is the normal method of working. When a machine is coupled direct the section should be isolated again.

The curves in the appendix have been carried beyond economical limits. They would not clearly show the limits if this were not done. Mr. Bridge's diagram (Fig. P) illustrates an arrangement of limited application. It becomes of more general application if all the machines have transformers or all feed direct. In either case, although differently described, the arrangement is in fact a four-section system on the ring principle.

My proposed limit of two spares has been a little misunderstood. In order to keep the investigation within practical limits, I have avoided dealing with units of mixed capacities, which offer so large a number of combinations and special conditions. The broad principles can all be deduced by taking the largest machine as the "unit" for the calculations. I have indicated in the footnote on page 270 that the provision of two spare units does not actually involve two machines of the largest size. I will show roughly how the provision of spares works out on growing plants—and practically all our plants are growing plants. I give below a hypothetical table illustrating the conditions in a plant which grows from 10,000 to 120,000 k.v.a. output, in which advantage is taken of the increased economy of large units, but in which an attempt is made to furnish no spares at all. It will be seen what the engineer is driven to provide in the way of spares, or he cannot reach the 40,000 k.v.a. unit.

Machines installed	Total capacity	Output just after addition	Output before next addition	Spares just after addition	Spares before next addition
	k.v.a.	k.v.a.	k.v.a.	Per cent	
1st 10,000	10,000	10,000	10,000	0	0
2nd 10,000	20,000	10,000	20,000	100	0
3rd 20,000	40,000	20,000	40,000	100	0
4th 20,000	60,000	40,000	60,000	50	0
5th 20,000	80,000	60,000	80,000	33	0
6th 40,000	120,000	80,000	120,000	50	0

The following table meets Mr. Bridge's suggested rule. Here we allow as a *minimum* that one of the largest machines shall be a spare, and this time we reach a unit of 30,000 k.v.a. It will be seen that the spares vary from 25 per cent to 250 per cent, although the sizes step up by only 50 per cent. With 100 per cent steps in size of unit, the proportion would be about 40 per cent minimum spares. These are properties of numbers and we cannot get away from them. The important feature is to note that a large part of the plant will be spare plant and to allow for this in considering the problem. This point has sometimes been overlooked, resulting in impracticable or extravagant recommendations.

Machines installed		Total capacity	Output just after addition	Output before next addition	Spares just after addition	Spares before next addition
		k.v.a.	k.v.a.	k.v.a.	Per cent	Per cent
1st	2—10,000	20,000	10,000	10,000	50	50
2nd	1—15,000	35,000	10,000	20,000	250	75
3rd	1—15,000	50,000	20,000	35,000	150	43
4th	1—20,000	70,000	35,000	50,000	100	40
5th	1—20,000	90,000	50,000	70,000	80	29
6th	1—30,000	120,000	70,000	90,000	71	33
7th	1—30,000	150,000	90,000	120,000	67	25

Where customers will purchase in the cheapest market it is impossible for designers to observe true economical limits, and I am in sympathy with Mr. Mitchell's comments. The stand-by relay should show a factor of safety in mechanical strength and heating limits when subjected to the severest fault current the circuit may carry and for the full time permitted by the relay and switch it controls. The current may be 100 times normal, and the time a second or more. The contacts must be reliable as they are seldom closed, and the delaying device must be of the most reliable type also. The stand-by relay has to stand up when everything beyond it may have failed.

By calculating reactances on a percentage basis we draw general conclusions in a simple form. The "ohmic value" is the value $2\pi n$ L, where n is the frequency and L the self-induction in henries, and is the most convenient for ordinary calculations.

Mr. Cowie's comments are based on experience on a large installation, and are coloured by unhappy experience with switchgear over-rated, over-stressed, or defective in design. Allowing for the difference in standpoint, I think we are in general agreement, but I should like to add a few qualifying remarks.

My recommendations for substation switchgear are given in the last paragraphs of Appendix 1, and cover Mr. Cowie's ground. For individual small consumers one cannot of course consider switchgear of "50,000 to 350,000 k.v.a. rupturing capacity." On the subject of gas production, many failures have been due to explosions of gaseous mixtures within the switch chamber, so gas production is one of the limiting features in rupturing capacity. Gas production rapidly increases where the rupturing limit is approached, and this corresponds to increased burning. I do not refer here to a burn-out but to excessive erosion. Following Figs. 2 and 3, I have recommended that artificial reactances should be located near to the part to be protected. These diagrams show the utilization of inherent impedance for the same purpose.

I am in complete sympathy with the suggestion that there is much room for systematic and well-considered experimental work on oil-switch designs, to demonstrate how an oil switch does its duty, what that work really is and how each separate feature can be made to contribute to it, and also the possibilities of a number of suggestions which have been made but never tested, as, for example, preventing gaseous explosion by the use of heat-absorbing material suitably disposed in the air space above the oil.

ADDRESS TO THE STUDENTS' SECTION.

By C. H. Wordingham, C.B.E., President.

(*Address delivered 22 March, 1918.*)

It is now some years since I had the pleasure of addressing you, and I am particularly glad again to have the opportunity of doing so during my year of office as President. I have always been keenly interested in the younger members of the Institution, and you may remember that I referred to them at some length in my Inaugural Address.* I propose now, rather than giving you a formal address, to have what I may call a chat with you, and I also propose to break away from the tradition according to which addresses of this kind are not open to discussion, and to invite you after I have finished to ask me any questions that may occur to you, and to make such suggestions as may seem to you likely to improve the usefulness of the Students' Meetings.

You are on the threshold of your careers. It is 36 years since I myself started as a Student; now I am approaching the sere and yellow leaf, while you are bourgeoning in the springtime of youth. I should like to gather some of the fruit of my long experience for your benefit, and to indicate in what way success may best be sought in the future that lies before you. When it comes to the last it will matter little what you have got; it will matter a good deal what you have done, but the thing of chief importance is what you are. In other words it is character that counts as the criterion of success when the end of life is arrived at. Character is a structure, and may be likened to a bridge one end of which occupies a small space in time, and, resting thereon, reaches forward to eternity. Every act is a member of that structure and determines its form and strength. A man is known by his character, and even here it is his most valuable asset. At this time character is of special importance because the flower of the nation has been killed off, and on those remaining rests the responsibility of the character of the nation. It is impossible therefore to exaggerate the importance of men like yourselves aiming high, and using every endeavour to raise the tone of the nation to the highest pitch.

The coming time is fraught with tremendous dangers, but it also presents magnificent opportunities. Everything depends upon the way in which problems that arise are dealt with. In the past, politics have presented few attractions to most of us; to many it has seemed that to whatever party the politician belonged the good of the nation has in many instances been sacrificed to the good of the party, with the result that numerous persons have viewed politics with disgust. Now, however, a new field seems to be opening up, and it is greatly to be hoped that men of ability and sense who in the past have given politics the go-by will now take a keen interest in them.

The Whitley Report is probably known to most of you, by name at all events. That Report is an epoch-making document. It lays down the principle that all those engaged in an industry should share in its management; and in the Industrial Councils which it advocates it provides an opportunity for the utilization of the brains of all those engaged in the industry, in whatsoever capacity they be employed. If only it be rightly apprehended by those of the nation who are generally connoted by the term "labour," they will find that magnificent opportunities are provided for those of their number who have the ability to rise to high positions in the State, and to exert a wonderful influence on its destiny. I myself have known working men of the highest integrity, of conspicuous ability with broad-minded principles, and one has only to cast one's eyes on some of the labour leaders to see of what the working class is capable. I firmly believe that employers will find in the working man, if he be taken into their counsels, a vast reservoir of strength for the nation, a reservoir which has so far hardly been tapped. If these opportunities be given to labour, and if labour has the wisdom to seek to attract into its ranks men of intellect trained in arts and sciences, they will go on from strength to strength and achieve for this nation a higher place even than it has occupied in the past. Employers should encourage by every means in their power the legitimate aspirations of the working classes, and, if they do this, they will find that a steadying influence is exerted on the unruly elements which undoubtedly exist, and what might be a disastrous development of destructive forces ending in the ruin

* *Journal I.E.E.*, 1918, vol. 56, p. 1.

of this country may be directed to its upward progress and prosperity.

One thing is made very clear in the Whitley Report, namely, that the Government only intends to recognize organized bodies of men. It thus becomes evident that every class in this country will have to be organized, including engineers. The Institution have in hand the promotion of a protective Association for its members, and I strongly advise all of you to watch carefully the development of this scheme, and to see to it that at an early stage in your careers you join the Association for the protection of your interests which is provided by the Institution, or rather I should say under its auspices. I look forward to the eventual federation of all electrical associations and organizations under the Institution of Electrical Engineers. I hope to see obtained in the near future a Royal Charter which will enable this to be done, the Institution being governed by a Grand Council on which representatives of all the outside but allied organizations will sit.

I should like to call your attention to a new organization which has recently been started, known as the "Engineering Training Organization." The Council of this organization consists wholly of representatives of Institutions, each Institution sending one, who is there as representing the Institution and not in his personal capacity. From this Council a small Executive Committee has been formed which carries on the business of the organization. Briefly the ideas underlying this scheme are to provide means for affording information to the parents of boys desiring to become engineers, to advise them as to the training necessary, and to bring the boys and their employers into contact with one another. In each works there will be an individual appointed to look after the interests of the apprentices and of the pupils. These individuals from the various works in a district will be in communication with one another, and will form local committees with representatives of schools and training institutions in the district, as well as with the local branches of engineering Institutions, such as our own Local Sections. In this way it will be ensured that the apprentices and pupils have their interests looked after in every works, and means will be provided to ensure uniformity of practice and the exchange of information. The formation of these district Committees will ensure that the peculiar needs of any given locality are catered for, thus avoiding any attempt to apply one cast-iron system to the whole of the country. The local Committees will be in communication with headquarters who will co-ordinate the work of all, and provide information to individual localities derived from various parts of the country, with a view to the improvement of local conditions. The universities, the technical colleges, the public schools, and the various engineering Institutions are all supporting this movement, and manufacturers also are largely interested. There is every prospect that through the agency of the Engineering Training Organization the courses in the universities will be brought more into accord with the needs of manufacturers, and manufacturers themselves will be brought to recognize the importance of the university training, and will throw open their works to receive university students. It is intended to advocate due provision being made for the sound development of all those who are learners, whether they be apprentices or pupils, and to provide for the apprentices a continuous record of their work, so that their future employers may have full evidence of their training and attainments.

The importance of proper education is growing from day to day, and it will be even more essential in the future than it has been in the past for the young engineer to be very fully equipped with all suitable tools in the way of training and attainments. There are certain to be great opportunities in the near future, in connection with the reconstruction rendered necessary by the unspeakable atrocities of the Germans, and I strongly advise you all to acquire a thorough knowledge of French and Spanish. We have every reason to hope that this nation will be engaged largely in the work of reconstruction in those countries which have suffered so severely, and we may look forward to a large share of the trade in countries formerly largely dominated by the Boches. I need hardly say what a magnificent field is presented by South America.

I presume that most of you are impressed with the desirability of obtaining some knowledge of works while you are yet at college, but I do not know that the advantage of keeping in touch with college work after you have entered an engineering shop is so fully recognized. After having been engaged in industrial work it is astonishing to find what a restful feeling there is in returning to academic precincts, and it tends greatly to maintain a high state of efficiency to come into occasional contact with the academic side.

I would strongly advise each one of you to begin early to keep your own record of salient pieces of knowledge bearing upon the particular branch of work that you are engaged upon, selecting your own subject. By instituting a system of filing at an early date in your career you will find that you are able to maintain an invaluable record which will be of the greatest possible assistance to you in after years. Without some such system there is a vast amount of misdirected effort, and a large proportion of your reading is lost through the absence of some simple system of recording what you have read.

Another point that I would urge upon you is to keep in touch with other sections of industry. Use every effort to avoid getting into a rut, but do not make the mistake of being for ever running about from one works to another, and in regard to your employment remember as a golden rule to "be on with the new love, before you are off with the old." In other words make sure of your new job before you give up the last one, however distasteful the latter may be.

PROCEEDINGS OF THE INSTITUTION.

46TH ANNUAL GENERAL MEETING, 30 MAY, 1918.

(Held in the rooms of the Institution of Civil Engineers.)

Mr. C. H. WORDINGHAM, President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting of the 23rd May, 1918, were taken as read, and were confirmed and signed.

The list of candidates for election and transfer approved by the Council for ballot was taken as read and was ordered to be suspended in the Hall.

The following donations were announced as having been received, and the thanks of the meeting were accorded to the donors:—

Benevolent Fund: A. H. Bate, P. Rosling, M. G. Simpson, Dr. S. P. Smith, and C. P. Sparks.

Building Fund: Professor A. Hay.

Library: The Library Association of the Athenæum, Messrs. Edward Bennis & Co., Ltd., Messrs. Constable & Co., Ltd., Sir Robert A. Hadfield, Bart., F.R.S., E. H. Hughman, Mrs. I. H. Lane, C. W. Mallins, P. D. Pederson, and R. Rankin.

Messrs. H. Boot and A. G. Collis were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the result of the ballot was declared as follows:—

ELECTIONS.

Members.

Poole, William John. Smyth, Christopher Hugh.

Associate Members.

Brotheridge, Thomas Raymond, Commissioned Electrician, R.N.
Ditcham, William Theodore Kildary.
Grote, Edwin Rudolph.
Hughes, Aubrey Everard.
Jones, Edward Walter.
Maunder, Richard Stanley.
Roberts, William.
Sergent, Raoul Sydney B.
Walker, Norman Saville, Captain R.E.
White, Walter.
Woods, Errol Forster.

Associates.

Macnaughton, Duncan James.
Sutcliffe, James Anderton.

Graduates.

Auber, Mohammad.
Campbell, Elliston Fauna.
Curzon, Percy John P.
Davies, David Reginald.
Edmiston, Alan Lesley.
Evans, Henry John.
Searles, Harold Everard.
Sylvester, Cyril.
White, Harry.

ELECTIONS—*continued.*

Students.

Ball, Eric Harold.
Barnes, Frederick Robert.
Budgen, Harry Percy
Fuke, Francis Cecil.
Kingaby, George William.
Porter, Alfred George.
Randall, John Edward E.
Rayner, Thomas Robert.
Shaw, John.
Steele, William Herbert.
Thomsett, Bernard.
Tilbury, Albert William.

TRANSFERS.

Associate Member to Member.

Andrews, John Robert.
Burr, James William.
Carter, Thomas.
de Guerrier, Frank Ernest.
Forrest, Frank.
Heppenstall, Frank.
Madden, Wyndham D'Arcy.
Moore, Albert Edwin.
Morgan, John David.
Nott, Harry Augustus, M.B.E.

Graduate to Associate Member.

Collett, Edward Percy.
Houghton, Samuel Birchall.
Kirkpatrick, Kenneth John.
Roy, Nagendra Nath, B.Sc.

Student to Associate Member.

Cursetjee, Noshervan Jehanghir.
Fenwick, William Oliver.
Rosen, Jessel.
Walker, Brian Bruce.

Student to Graduate.

Dunn, Spencer William, B.Sc. (Eng.).
Fawcett, Herbert.
Mellonie, Stanley Richard.
Sarkar, Chandra Sekhar.
Stevens, George Carson.

The President then gave a summary of the Annual Report of the Council for the year 1917–18 (see p. 330).

The PRESIDENT: In order to prevent any misunderstanding I should like to say a few words as to the statement in the Report regarding the Metric System. The question referred to in the Report arose in connection with the work of the Engineering Standards Committee. The Main Committee of the Engineering Standards Committee gave permission to the Sectional Electrical Committee to draw up its Specifications in terms of metrical measures if the section of the electrical trade affected so desired. As Chairman of a number of Panels I was one of those who had to give effect to this decision, and I found that whilst one Panel wanted British measures another wished to have

metrical measures. We eventually got into such a position that we had a cable lug which was specified in metrical dimensions as regards its shape but had two holes through it both of which were specified in British measure. Things got into such a tangle that the Engineering Standards Committee asked the electrical industry to come to a definite conclusion as to what it wanted. The point at issue was not merely the printing of two parallel columns of figures, but whether the fundamental dimensions which were to be standardized were to be standardized in even round figures of millimetres or even round figures of inches, that is to say, whether the fundamental dimensions should be metrical or British. Anybody could work out the equivalents and have them printed, but that was not the point. This matter was a very important one, and the Institution therefore called together a Conference of the British Electrical and Allied Manufacturers' Association, the Cable Makers' Association, the Tungsten Lamp Association, and the Battery Makers' Association. The discussion was confined to the one narrow issue. That is what I want to make plain, namely, that this is not a pronouncement on the question of metric versus British measurements, but merely on the one question: Should the Specifications of the Engineering Standards Committee continue to have the fundamental dimensions which are standardized worked out in even British units, or should a change take place now, at this time, and the fundamental measurements be made in metric units? That Conference was unanimously of the opinion that this is not an appropriate time to make that change in the practice of the Engineering Standards Committee. That is what the resolution means, and nothing more. It does not commit the Institution or the industry to any general pronouncement on the metric system; it is simply directed to that one point which I have tried to make clear. I think I was justified in explaining that point in order to avoid any misconception of the attitude taken up by the Institution on the metric question generally.

The President then moved "That the Annual Report of the Council for the year 1917–18 as circulated be received and adopted."

This resolution was seconded by Mr. C. P. Sparks, and after remarks from Mr. H. Boot, Mr. H. Allcock, Mr. E. G. C. Barton, Mr. E. T. Williams, Mr. G. Semenza, Mr. S. Evershed, and Mr. P. M. Baker, and the President having answered the questions which had been asked, the resolution was put to the meeting and unanimously adopted.

Mr. J. E. Kingsbury then moved the following resolution: "That the Statement of Accounts and the Balance Sheet for 1917 as presented be received and adopted."

Mr. J. E. Kingsbury: The form in which the Accounts are submitted to the members renders it unnecessary for me to go in detail through the various statements and make comparisons with the previous year, because that information is on the face of the Accounts. It may be desirable, however, to make some remarks on one or two items and to refer to general tendencies. The Income and Expenditure Account indicates the characteristics of the year. There has been an increase in membership as the President has told us, and one of the most gratifying features of the Income Account to my mind is the increase in subscriptions and entrance fees there shown. If it had been the other way about, we ought not to have been surprised, under the circumstances now ruling. Then the absence from our own building as well as the circumstances of the year have somewhat reduced the activities of the Institution—I do not mean the activities of the Council, the Committees and the staff, because I believe those activities have been even greater than usual—but the work represented, for example, by the Expenditure side has been somewhat reduced. The whole tendency of the year has been for increases in costs calling for restrictions where possible. There is an increase in expenditure in normal items, but that increase is small compared with what it would have been if our normal output had been continued. For example, the *Journal* has cost us almost the same as before, but it has been somewhat strictly rationed. The income from the Institution building and the expenditure on the building have both made material changes during the past year, and combined they have led to a balance of income which the Council have dealt with in a way which somewhat anticipates the future. The activities which have been somewhat curtailed will, we hope, before very long be renewed. I will not prophesy as to any particular date, but we feel satisfied that we shall go back to our own building some time or other, and we hope before very long. On the other hand, we cannot expect to get as much for our money in the future as we have in the past; and, the financial position of the year being somewhat abnormal, the Council have thought it advisable—not from any idea of pessimism or as prophets of evil—to look forward to a possible contingency of an unsatisfactory character from the income side. They have therefore, from the income of the year, placed a sum of £3,000 to a Reserve Fund, which is a new feature of the Revenue Account. That will be available in case any adverse contingencies arise, and that fund may then be drawn upon without trenching on the General Fund. If happily no adverse contingencies should arise, it will always be available for a very desirable object—the reduction of the debt on the building. Turning to the Balance Sheet, we have in the Report a statement of the present position. Perhaps I might give members some kind of statement in other words by indicating exactly what the £84,780 of assets comprises. The Institution building and the Tothill-street property, less the mortgages and plus the sinking fund, stand for £60,375; in investments there is £19,466; in cash £671, and in collectable assets, which I should call as good as cash, £3,733; a stock of material of £794; library and furniture, £4,430; a total of £89,469; from which we have to deduct liabilities amounting to £4,689, leaving the net amount, in accordance with the Report, of £84,780, which is some £6,000 in excess of last year. That, of course, includes the Reserve

Fund which I have mentioned. It is possible that that may be reduced at some time in the future, but we hope not. I think that covers the ground, but if there are any questions which any member would like to ask I shall be very glad to answer them as clearly as I can.

The resolution was seconded by Mr. C. P. Sparks.

Mr. E. G. C. Barton was of opinion that the value placed on the Library in the Balance Sheet was too low.

After Mr. Kingsbury had replied to a question by Mr. W. B. Esson, the resolution was put to the meeting and carried unanimously.

The PRESIDENT: I now have to propose "That the best thanks of the Institution be and are hereby accorded to the Council of the Institution of Civil Engineers for the kind hospitality extended by them to the Institution in placing their meeting rooms and Library at its disposal."

The resolution was carried by acclamation.

Mr. W. B. WOODHOUSE: I should like to move "That the best thanks of the Institution be accorded to the following officers for their valuable services during the past year:—(*a*) The Honorary Secretaries of the Local Sections, and the Local Honorary Secretaries and Treasurers abroad; (*b*) the Honorary Treasurer (Mr. J. E. Kingsbury); (*c*) the Honorary Auditor (Mr. Sidney Sharp); and (*d*) the Honorary Solicitors (Messrs. Bristows, Cooke, and Carpmael)."

Mr. W. B ESSON: I have much pleasure in seconding that resolution.

The PRESIDENT: I think that under the exceptional circumstances I should like to associate this vote of thanks with Mr. Semenza, our Honorary Secretary in Italy. We so seldom have the pleasure of seeing our foreign Honorary Secretaries that this is rather a special occasion. I should also like to emphasize the splendid work done by the Local Honorary Secretaries. Their duties are very onerous; they do not come into the limelight, but on them largely depends the success of the Institution.

The resolution was then put to the meeting and carried unanimously.

The President then moved "That Mr. Sidney Sharp be elected Honorary Auditor and Messrs. Allen, Attfield & Co., Auditors for the year 1918–19."

The resolution was carried by acclamation, and the meeting adjourned at 8 p.m.

BENEVOLENT FUND.

20TH ANNUAL GENERAL MEETING, 30 MAY, 1918.

Mr. C. H. WORDINGHAM, C.B.E., President, took the chair at 8 p.m.

The minutes of the Annual General Meeting of the 17th May, 1917, were taken as read, and were confirmed and signed.

The President moved, and Mr. Sidney Sharp seconded, that the Report (see below) of the Committee of Management and the Statement of Accounts (see page 343) for the year 1917 be adopted. After remarks by Messrs. S. Evershed, W. B. Esson, L. B. Atkinson, H. W. Kolle, W. R. Rawlings, and J. E. Kingsbury, in regard to obtaining further subscriptions to the Fund and transferring to the Capital Account a portion of the amount of £2,062 12s. 2d. standing in the Balance Sheet to the credit of Income and Expenditure, the resolution was put to the meeting and adopted.

On the motion of the President, seconded by Mr. H. W. Kolle, Mr. Sidney Sharp and Mr. J. Attfield, F.C.A., were re-elected Honorary Auditors.

The President reported that the Council had appointed the following Committee of Management for the year 1918–19:—

The President (C. H. Wordingham, C.B.E.), *ex-officio*.

W. B. Woodhouse W. Ll. Precce G. S. Ram W. Lang Sir W. Slingo C. P. Sparks	Representing the Council.
F. Gill C. C. Hawkins H. W. Kolle	Representing the Contributors.

and the

Chairman of each Local Section in the United Kingdom.

The meeting then terminated.

REPORT OF THE COMMITTEE OF MANAGEMENT FOR THE YEAR 1917.

Capital.

The Capital Account stood on the 31st December, 1917, at £4,642 3s., all of which is invested.

Income.

The Statement of Accounts shows that the total receipts during 1917 were as follows:—

	£	s.	d.
Dividends on Investments ..	228	19	4
Interest	6	17	9
Annual Subscriptions ..	113	10	6
Donations of £5 and over ..	56	5	0
Donations under £5	24	6	6
	£429	19	1

The accumulated unexpended Income amounts to £2,062 12s. 2d., of which £1,693 2s. 3d. is invested.

Subscribers and Donors in 1917

ANNUAL SUBSCRIBERS,

H. Alabaster
G. F. Allom
S. Beeton
L. Birks
I. Braby
S. E. Britton
J. Burns
R. A. Chattock
W. Church
F. W. Clements
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J. Devonshire
B. M. Drake
Dr. C. V. Drysdale
W. Duddell, C.B.E., F.R.S.
K. Edgcumbe
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M. Farrer
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F. E. Gripper
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B. B. Granger
C. W. Gwyther
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W. C. C. Hawtayne
K. Hedges
D. Henriques
J. S. Highfield
H. Hirst
H. C. Holroyd
S. Insull
E. S Jacob
Dr. G. Kapp
A. C. Kelly
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J. E. Kingsbury
H. W. Kolle
A. E. Levin
J. R. P. Lunn
Sir Henry Mance, C.I.E.
W. Mead
J. W. Meares
S. W. Melsom
L. B. Miller
W. M. Mordey
W. M. Morrison
W. C. Mountain
A. J. Newman
Col. Sir A. M. J. Ogilvie, K.B.E., C.B.
C. Oliver
Bt.-Lieut.-Col. W. A. J. O'Meara, C.M.G.
E. Parry
The Hon. Sir C. A. Parsons, K.C.B., F.R.S.
W. H. Patchell
C. C. Paterson, O.B.E.
Major F. G. Payne, D.S.O.
A. H. Preece
W. L. Preece
N. Prentice
H. F. Proctor
G. S. Ram
W. R. Rawlings
T. Rich
R. Robertson

ANNUAL SUBSCRIBERS—*continued.*

S. R. Roget
S. A. Russell
S. G. C. Russell
E. Seddon
S. Sharp
J. F. Shipley
A. Siemens
M. G. Simpson
H. A. Skelton
Sir John Snell
C. P. Sparks
C. Stewart
A. J. Stubbs
H. W. Sullivan
W. C. P. Tapper
E. E. Tasker
C. H. R. Thorn
A. P. Trotter
W. B. Woodhouse
J. H. Woodward
C. H. Wordingham, C.B.E.
W. Young

DONORS.

P. F. Allan
The Association of Municipal Electrical Engineers
A. H. Bate
A. H. F. Boughey
A. Castello-Sosa
H. C. Channon
J. D. Dallas
The Diesel Engine Users' Association
L. H. Euler
V. W. Gill
Messrs. W. T. Henley's Telegraph Works Co., Ltd.
H. V. Henniker
R. H. F. Houstoun
W. E. Lane
F. W. Main
C. H. Merz
H. Parry
W. Pintner
H. A. Ratcliff
Dr. A. Russell
E. K. Scott
S. Simpson
Dr. S. P. Smith
J. K. Stothert
The "Twenty-five" Club
T. C. T. Walrond
H. W. Wilkinson
S. L. Wong

Among the larger donations received during the year were one of £25 from Messrs. W. T. Henley's Telegraph Works Co., Ltd., and two (a donation of £15 15s. and a special War donation of £5 5s.) from The "Twenty-five" Club.

The Committee of Management desire to acknowledge their indebtedness to these and the other donors and subscribers who have supported the Fund, but they venture once more to urge upon the members the pressing need for a more generous support of the Fund. Apart from donations, the Committee will be grateful for annual subscriptions even of small amounts.

Grants.

Fifteen applications for assistance were received in 1917 and the Committee, after due investigation, made grants in 14 cases. Four grants were made of £25, one of £15, six of £10, one of £9, one of £8 15s., and one of £5, a total of £197 15s. for the year.

Wilde Benevolent Fund.

The Capital Account stood on the 31st December, 1917, at £1,846 4s. 6d., the whole of which is invested and brings in an annual income of £55 17s.

The balance standing to the credit of the Income Account at the end of 1917 was £583 15s. 4d., of which £540 14s. 8d. was invested and brings in an annual income of £23 10s.

No grant was made from this Fund during the year.

OBITUARY NOTICES.

CAPTAIN GEORGE LEONARD ANDREWS, R.G.A., was killed in action in France on the 3rd May, 1918, while proceeding to an observation post. He had been only three weeks in France with his battery, after having acted as *Liaison* Officer and Temporary Major to a Portuguese brigade of artillery for 12 months previously. During this period he did most valuable work by lecturing and by translating several of the gunnery books into Portuguese. Having successfully despatched the brigade overseas he could have continued his work with other drafts, but, as he remarked to the writer, he did not wish to have a "soft job" at home, and preferred to be doing his share during this year's campaign. With his death in action there ended the life of a very gallant gentleman. Captain Andrews gave up the important post of General Manager and Engineer to the Pernambuco Tramways and Power Company in 1914 to come home and offer his services to his King and Country. He was a widely experienced engineer and a first-rate mathematician, so that he had no difficulty in obtaining a commission, though he was then over the age limit. After undergoing the necessary special training he spent some time at home at an important coast station, and then applied to go to France, where he was in several actions. Things then became quieter in France, and he volunteered for service in the East and passed the winter six-months of 1915–16 in Egypt and Syria, after which he returned to France and was through the battle of the Somme. He was then appointed to special service with the temporary rank of Major. He was a B.Sc. (London) and a B.Eng. of Sheffield, and, in addition to being a Member of the Institution, was also a Member of the Institutions of Civil and Mechanical Engineers. He was much travelled, a good sportsman and horseman, and had undertaken two explorations into the undeveloped parts of Brazil. He served his time with the Brush Electrical Engineering Company, and developed his experience in tramway construction and operation at Kidderminster, Madrid, and Hull. Thence he proceeded to Sunderland to act as chief assistant, first to Mr. (now Sir John) Snell, and afterwards to Mr. H. England. He was then offered the post of Engineer to the Lisbon Tramways, which he held for some years until he was offered, and accepted, the post of General Manager and Engineer to the Pará Electric Railways and Lighting Company. This he held for several years, after which he started to practise in Rio de Janeiro. Being again offered the important post at Pernambuco, for which he was so well suited, he decided to take it up and had begun constructional work when the war broke out. A life of much promise has been cut short—fearless and well used to the control of men, of great initiative and resource, he made a splendid soldier and most efficient officer. Had he survived the war, he would have gone far in his profession. He was elected a Member of the Institution in 1909.

ROBERT WINTHORP BLACKWELL died, after a very short illness, on the 28th March, 1918. By his death the electrical profession loses one of the few remaining and best-known pioneers of electric traction, and one whose name has been intimately connected with the most important branch of this profession both in this country and in the United States for the last 35 years. Born in New York in 1858 he was educated at Princeton at the John C. Green School of Science connected with that University, receiving the degrees of B.A. in 1879 and M.A. in 1882. After leaving college he passed through the Law School of Columbia College in the City of New York, receiving the degree of LL.B. in 1881 and being admitted to practice at the New York Bar in the same year. Shortly after passing the Bar he entered the office of the Gramme Electrical Company, whose shareholders were the Brush, Edison, Fuller, Jablochkoff, Thomson-Houston, United States and Weston Electric Light Companies, it being the first attempt to consolidate electric light and power interests into one control. From 1881 to 1884 he was successively its Secretary, Treasurer, and Manager, his connection with the Company in a legal capacity disappearing almost entirely as he became more and more interested in the engineering side of its work. During these years he was also Honorary Secretary of the General Committee of the United States for the reform of patent legislation, composed of all the principal inventors of the United States and representatives of all the companies whose success depended upon the value of their patent property. He was also Honorary Secretary of the General Committee of the State of New York on underground electrical communication, composed of all companies owning electric wires within the State. In 1883 he became the Secretary of an electric traction syndicate, which in 1884 became the Bentley Knight Electric Railway Company. This Company can claim to have been the first to run an electric car in a city street by means of continuous conductors from a central power station. From 1884 to 1890 he was successively the Secretary, Treasurer, Managing Director and Chairman of this Company. In 1883 to 1886 the work of this Company was carried out at the Brush electrical works at Cleveland, and at the Rhode Island locomotive works of Providence, Rhode Island. In 1887 its machines were made for it, and under its supervision by the Thomson-Houston Electrical Company of Lynn, Mass., the first railway motors ever made by the Thomson-Houston Company were erected and operated by him at Moonsocket, Rhode Island, and Allegheny, Pa. In 1888 to 1889 he established works in the City of New York for the Bentley Knight Company in which were manufactured electric dynamos, motors, trucks, etc., the first 60 machines used by the West End Street Railway of Boston being of this make. Early in 1890 he sold out all his electrical interests to the Thomson-Houston Electric

Company and came to Europe for a holiday ; but after spending a year in travelling about he settled down to business. Mr. Blackwell, as a contemporary of Sprague, Vanderpool, and Edison, was intimately associated with the great pioneer work carried out in the United States between 1883 and 1889. Speaking at the sixth annual meeting, in Philadelphia, of the Street Railway Association on the 19th October, 1887, Mr. Blackwell said : "We entered the electric city tramway field long in advance of all others, and we believe that electric street railways for city service can be used effectively only where the power to drive the car is transmitted to it from a generating station." How true this prevision was has been amply demonstrated, although at the time many thought the future lay with the storage battery. In 1890 he became associated with Messrs. Greenwood and Batley of Leeds, in conjunction with whom he opened an office in London for the purpose of introducing electric traction on the tramway systems of the United Kingdom. Speaking about the United States before the Institution in 1892, Mr. Blackwell said : "The public has thoroughly supported those tramways which have introduced electricity, and has rewarded their enterprise by greatly increased patronage. That electric traction will receive the same acceptance here that it has already gained across the water I do not doubt." Time more than justified Mr. Blackwell's anticipations, although several years of arduous pioneering work were necessary to overcome the opposition of inertia and vested interests before electric traction was definitely established in this country. In 1894 Mr. Blackwell founded the firm of Robert W. Blackwell & Company. He exhibited in 1897 at the Brussels Exhibition, and was a member of the International Jury. It is interesting to note that although American born and a very prominent member of the American Society in London, all Mr. Blackwell's associates and staff were British, and the prescience shown by him in selecting men, and the kindly assistance and advice and loyal support he always gave his staff, have resulted in the launching of a great many engineers into the prominent positions they now hold in many parts of the world. His motto always was : "You cannot afford to do bad work ; the best only is good enough." He was a member of the Royal Automobile, Ranelagh, and City Liberal clubs, and always retained his membership of the Manhattan, Lawyers, and University clubs of New York. He was a prominent mason, was past master of the Lodge of the Nine Muses and the founder of the American Columbia Lodge, and was awarded London rank for his masonic services. His memory will be kept green in the hearts of all those who had the privilege of his friendship, and nothing is more characteristic of him than the opinion expressed by one of his oldest friends, "Blackwell was as straight as a die." He joined the Institution as a Foreign Member in 1891 and became a Member in 1895. P. D.

CAPTAIN WILLIAM LEONARD CARTER, R.E., was born in Shanghai in 1877, and was educated at St. Paul's School, London, continuing his studies in a technical direction at the Central Technical College. He served as a 2nd Lieutenant in the East Lancashire Regiment during the South African War. Later he went to Hong-Kong to the China and Japan Telephone Company, of which he became the local agent and manager, a position which he held for about 13 years. He was very interested in the formation of the Hong-Kong Local Centre of the Institution, becoming the first Chairman of the Local Centre in 1915. Soon after the outbreak of war he became Adjutant of the Hong-Kong Volunteer Reserves, with the local rank of Captain. He resigned this post subsequently to become O/C, R.E. stores. His death from enteric fever took place at the Military Hospital, Hong-Kong, on the 4th July, 1917. He joined the Institution as a Student in 1897, was elected an Associate in 1898, an Associate Member in 1902, and a Member in 1913. A. G. W

ERNEST JAMES COCHRANE was born in 1871 and received his early education in England, completing it at high schools in Austria and Germany and by attending evening classes at Finsbury Technical College. He went in 1890 as pupil to the Acme Electric Works, Chalk Farm, London, subsequently being engaged by Messrs. H. W. Hooper & Company of Hanover Square, London, and the Electric Construction Corporation of Wolverhampton. In December 1895 he was appointed Chief Assistant Engineer in the employ of the Electric Supply Company of Western Australia at Coolgardie, subsequently becoming Resident Engineer and Manager. In January 1900 he became Assistant Engineer to the Electric Supply Company of Victoria, afterwards being appointed Assistant Engineer and Manager and, later, Acting General Manager under power of attorney. Whilst with that Company he designed the lighting, power, and tramway undertakings of Fremantle, Bendigo, and Ballarat, superintending the erection of the works at Bendigo and Ballarat and later being manager of these undertakings In September 1909 he was appointed Chief Assistant Engineer in the Electric Light Department of Sydney, afterwards becoming Deputy General Manager, a position which he held until September 1915. This period marked the most rapid growth of the Sydney undertaking and Mr. Cochrane supervised both the design and the carrying out of the extensions. In 1913 he paid a visit of several months to Europe and America, and returned to Australia with his knowledge of the latest practice in central station design brought up to date His health suffered owing to his excessive concentration on his work, and it was hoped that when in 1915 he became Engineer and Manager of the City Electric Light Company of Brisbane the lighter duties entailed by the smaller station at Brisbane would enable him to recover his health. From the day he joined this Company, however, until about four weeks before his death, in the summer of 1917, he worked unceasingly, both during business hours and also during the evenings, in connection with the conversion of the undertaking from a three-wire continuous-current system to a three-phase system. He was elected an Associate of the Institution in 1896 and a Member in 1917. W. M. L

JOSEPH P. DAVIS died on the 31st March, 1917, at Yonkers, New York, in his 80th year. He was born at Northborough, Mass., and was educated at Rensselaer Polytechnic Institute. He served as Assistant Engineer of the Brooklyn Waterworks and Chief Engineer of the Brooklyn Park Department. The St. Louis Waterworks and the Lowell (Mass.) Waterworks were constructed under his supervision. For many years he was Chief Engineer for the City of Boston and was also Consulting Engineer to the Metropolitan Water Supply Commission of Massachusetts which built several very large dams, reservoirs, and aqueducts. He was also Consulting Engineer at various times to the Metropolitan Sewerage Commission of Massachusetts and the Croton Aqueduct Commission of New York. In the electrical field, he was perhaps even more distinguished. He was one of the charter members of the American Institute of Electrical Engineers in 1884, and was the first to preside at a meeting of that body. He was at one time chief engineer of the American Bell Telephone Company and its successor the American Telephone and Telegraph Company. He did early and important engineering work in connection with the first underground telephone wire experiments in America, having laid and constructed such systems in New York, Boston, and elsewhere at a time when this art was distinctively new and experimental. He also designed and laid the first underground telephone system for New York and Boston, and, while still in his prime, designed telephone systems for Chicago, Philadelphia, and other cities. To the design of telephone machinery, cables, and apparatus, he also gave successful attention. He would, in fact, have been much better known but for the fact that so much of his pioneer work was done just before the period of the great modern developments of which he may be said to have laid some of the foundations. He was elected a Foreign Member of the Institution in 1887 and a Member in 1911.

T. C. M.

WILLIAM DU BOIS DUDDELL was born in 1873 and died on the 3rd November, 1917. It is told of him "that when he was only four years old, he was given a model mouse as a toy, and, not satisfied with its immobility, took the works from a small clock and fitted them unaided into the interior of the mouse, turning it into a successful automobile. From that time forward his nursery became a fairyland of automatic toys, all made by himself, and mostly grouped so that several separate toys went through their movements at once, all worked from a central source of power." Owing to his delicate health, his people stayed for many years at Cannes, where he was educated at the College Stanislas. He never went to a big school. Until he was past the age of 20, his parents never knew if he would live beyond the current year. He never had, therefore, the chance of gaining the self-confidence which success in field sports gives to a boy, and which is such a valuable feature of the education of young Englishmen. He was always fascinated by a fine piece of mechanism, and from his earliest years was made responsible for all the clocks in the house. When, later, he went to serve his apprenticeship with Messrs. Davey Paxman at Colchester, his landlady used to complain that all his friends came and left their clocks "on her doorstep." Afterwards he studied under the late Professor Ayrton and Professor Mather, and worked for many years at the Central Technical College He was always one of Ayrton's favourite students, and his success was one of the greatest delights that Professor Ayrton ever enjoyed. When he began work there, the problem of the delineation of the wave-forms of alternating currents was being studied at the laboratories, and Duddell at once became engrossed in the subject. I was working with him on the wave-forms of the alternate-current arc, and we were using a laborious point-by-point method of plotting the waves of current and potential difference. He had set his mind on the production of an instrument that would record the curves instantaneously, and at this problem he worked continuously. Duddell was attracted by the bifilar type of instrument which had previously been tried by Blondel. He made the first instrument at home in his workshop, using flat phosphor bronze strip for the vibrator, and brought it along to test; it gave promise of success, but the damping was ineffective, and he set to work to find a method of damping the motion of the strips which would enable the instrument to record a true curve. In the end Duddell made a separate channel for each strip, with walls of extraordinary thinness, the channels being filled with a viscous oil, and succeeded in obtaining critical damping, thus making the instrument a practical success. Next arose the problem of light, and a long time was spent in designing the most efficient system possible. It was characteristic of his thoroughness and patience that he was never satisfied until he had obtained the best results that he thought it possible to achieve in every detail of his apparatus, and his standard was a very high one. The first oscillograph was designed by eye, but it is remarkable that when the complete theory was worked out, the best dimensions possible differed very little from those which had been chosen by Duddell by that instinct which is the sure sign of scientific genius. When his instrument was complete in every detail he showed it to the Institution, and no one who saw that demonstration is likely to forget the occasion. It was the finest proof of his extraordinary powers that could be given, both as a designer of new instruments and as an expositor, for his exposition, in both its clearness and directness, charmed his audience so completely that Mr. Mordey, who opened the adjourned discussion, admitted that "his heart was fuller than his head" when he had moved the adjournment at the previous meeting.

In 1901 he produced a classical paper on the "Resistance of the Electric Arc" which was presented to the Royal Society; this paper was the result of over two years' continuous research. During the work Duddell discovered the "singing arc." He was trying to pass a high-frequency current through the arc by using a condenser and inductance shunted across it, when he discovered that the arc itself, under these conditions, would produce oscillations. This part of the paper was developed later in another paper read before the Institution on "Rapid Variations of Current

in the Direct-current Arc," also accompanied at the meeting by another brilliant demonstration, which ended with the playing of "God Save the Queen" on the arc by means of a specially arranged key-board. This phenomenon is the scientific foundation from which Poulsen subsequently developed his high-frequency arc generator, which is now being used on a large scale for producing the continuous oscillations employed in long-distance radio-telegraphy. Another feature of interest in his Royal Society paper was the use of a very high-frequency alternator. In order to measure the resistance of the arc with a current of so high a frequency that the alternations could not produce any sensible variations in its temperature, Duddell built an alternator giving 120,000 periods per second, a frequency much higher than had been attempted by any previous experimenter with a mechanically driven machine. In 1905 he read a paper with Mr. J. E. Taylor on "Wireless Telegraph Measurements" which described a number of quantitative tests (made with an instrument which he himself had designed) on the variations of signal strength with varying heights of antennæ and varying distances between them. In this subject he always showed the keenest interest, and he had in his own laboratory in Victoria-street a small antenna with which it was his delight to read signals from distant stations, of very long wave lengths. The antenna was of relatively small proportions, and the records which he obtained with it were a remarkable tribute to his experimental skill. In 1907 he was elected a member of the Royal Society and in 1912 was awarded the Hughes Medal. In 1911 he read a paper to the Physical Society on a vibration galvanometer, which displayed all that care and refinement in detail that was so characteristic of him. One of his most useful inventions was the Duddell thermo-ammeter. This instrument was a development of the Boys radio-micrometer, but was modified in its final form so as to provide a portable instrument which can be used for the measurement of the highest frequency currents with accuracy and certainty. He was also responsible for one of the best patterns of Einthoven galvanometer and for a twisted-strip galvanometer of great sensitiveness. Duddell held many prominent positions in the scientific world. He was president of the Commission Internationale de Télégraphie Sans Fils and presided over the conference held in Brussels in 1914, being largely responsible for the preparation of the programme of work which was ultimately decided upon. In 1907 he was President of the Röntgen Society and was a Vice-President of the Wireless Society of London. He occupied the office of President of the Institution for two years, from 1912 to 1914, succeeding Dr. Ferranti, and he did much to set on a proper working basis the new schemes and methods that had been inaugurated in the period of Ferranti's presidency His election to the office of President was a recognition not merely of his eminence in his profession, but also of the enormous amount of energy he put into the routine work of the Institution. He acted for many years as Chairman of the Papers Committee, and displayed all those qualities of tact and sound judgment which are so necessary for the efficient conduct of the work of this Committee. The Chairmanship of the Papers Committee of the Institution is, perhaps, the most responsible position, next to that of President, that the Institution has to offer, for on the papers read before it depends more than anything else the success of the Institution's work. It is no exaggeration to say that the credit of the Institution rose appreciably during the time that Duddell was in charge. He did a great deal for the Library, in which he always took an untiring interest, he was responsible for the initiation of the Lending Library, and the Museum was a child of his own creation. He never lost a chance of acquiring an interesting specimen, and the members have to thank him for much in this direction. He gave a great deal of valuable help and advice in connection with the experimental equipment provided in the new building; his own skill and experience as a demonstrator were invaluable, and he placed them without stint at the service of his fellow members. His second Presidential Address in November 1913 on "Pressure Rises" was, perhaps, his most notable achievement as an expositor: the experiments were all difficult and required great skill in their performance, but they were all successful, and his model of the oscillating arc was a triumph of the demonstrator's art. He had a great gift of clear exposition. he never read a paper or lecture, but talked about his experiments with such obvious interest and delight that he fascinated his audience and made them as enthusiastic as he was himself about what he was showing them. Another lecture which showed Duddell at his best was the one he gave to the British Association at Leicester, on the "Arc and the Spark in Radio-telegraphy." In the course of it he passed several amperes of high-frequency current through his body and some of those present afterwards remonstrated with him at the possible risk he ran in so doing He gave a course of Christmas Lectures for children on "Signalling" at the Royal Institution which delighted them by the ingenuity of the experiments and the unfailing skill with which they were shown. He also delivered Royal Institution discourses on "High Frequency Currents" and other subjects. He was a member of the Advisory Board to the Department of Scientific and Industrial Research, and of the Board of Inventions and Research of the Admiralty.

Duddell was no mean linguist, and those who have heard him conduct an International Conference will remember the wonderful skill he showed in reconciling the points of views of men of different nationalities It is an unspeakable grief to his friends that he has died so young, though few men have ever achieved so much in so short a time, but he worked himself to death; he was always in his office or laboratory and he hardly ever took a holiday. He has left behind him a record of which any man might be proud. Had he been gifted with strength of body at all comparable with his gifts of intellect, there is no limit to what he might have accomplished. Yet with all his brilliance he was so unassuming and kindly that all who met him became his friends He was an enthusiast for science, and a great man of science, but he was also one of the kindest natures that have ever lived. That he reached the highest possible positions in his profession

was an evidence of his innate ability, and he will long be remembered as one of the best friends the Institution has ever had.

He joined the Institution as a Student in 1894, was elected an Associate in 1897, an Associate Member in 1901, and a Member in 1904. He served as a Member of Council from 1901 to 1908, as Vice-President from 1909 to 1912, and as President from 1912 to 1914. He also served as a trustee of the Benevolent Fund from 1914 until his death. E. W. M.

Lieutenant-Colonel A. H. DUMARESQ, R.E., who died very suddenly at the age of 47 on the 31st May, 1917, had been closely associated with the electrical branches of the duties of his Corps for the greater part of his service. Immediately after completing his general course of instruction as a young officer at Chatham in the summer of 1891, he was sent to Gosport for a two months' course in submarine-mining, which at that time and for some years longer formed a branch of the duties of the Corps of Royal Engineers. On completion of this course he returned to Chatham until the summer of 1892, when he was transferred to Cork for duty with a Submarine-mining Company. His duties here included the running of the coast-defence searchlights and of the Brennan torpedo installation, at that time established in the harbour. In the early part of 1894 he returned to Chatham for duty as Assistant Instructor in Electricity at the School of Military Engineering, in which post he remained for nearly 6 years, until shortly after the outbreak of the South African War. During his tenure of this appointment he was elected an Associate of the Institution. In February 1900 he was sent to South Africa for duty with a field searchlight section, where he remained until January 1901. He was gazetted Captain during his voyage out and received the Queen's Medal with clasps as a result of his part in the campaign. On his return from South Africa he was appointed to a post in the office of the then Inspector-General of Fortifications at the War Office, where he remained for 5 years. His duties here were entirely concerned with the administration of the various electrical services connected with the Army, and he was closely associated with the inception and completion of the War Department power station and distribution system at Aldershot, which was then, and is now, the largest War Department installation in existence. It was during this period that he was elected a Member of the Institution. On the conclusion of this appointment he served for 3 years in Egypt, during which time he received his Majority. He then returned to Chatham as Chief Instructor in Electricity, where he remained for 3½ years. In September 1912 he was appointed Inspector of Electric Lights at the War Office, in which post he remained until his death. For his services in this post during the present war he was promoted Lieutenant-Colonel by brevet (receiving his substantive rank at the beginning of 1917) and received the Croix d'Officier of the Legion of Honour from the President of the French Republic. G. L. H.

ALFRED EGGINGTON, who was born in Lichfield, Staffordshire, on the 26th January, 1841, and died at Rome on the 7th March, 1917, was elected an Associate of the Institution in 1872, and a Member in 1877. He entered the telegraph service in 1857, in the Submarine Telegraph Company, and the Government service three years later under an engagement to proceed to the Malacca Straits to work the Rangoon cable. He joined the first of the three large steamers chartered by Messrs. Siemens and Halske, the *Queen Victoria*, which, after various minor disasters and delays, ran aground at Wilderness Point, under Mount Edgcumbe, and became a wreck. He then entered the United Kingdom Company, which was then fighting its powerful rivals, the Electric and Magnetic Companies, and in 1861 accepted an appointment under Messrs. Glass, Elliott and Company to proceed to Italy, to supervise the transit of the English telegrams to and from the East. In 1862 he was appointed to Bengasi station (Barbary), and after four years in Africa returned to Italy. In 1868 he was clerk in charge of the Turin office of the Susa-Modica line, belonging to the Telegraph Construction and Maintenance Company, and remained there until appointed by the new Société du Câble Française as office superintendent at Brest. He returned to Italy at Christmas 1869 to become general superintendent of the above-mentioned Susa-Modica line. Since that time until his death he represented the Eastern Telegraph Company in Italy, his headquarters being at Rome. King Humbert some years ago conferred upon Mr. Eggington the Cross of the Crown of Italy and the title of Chevalier. In 1887 he was promoted to a higher grade of the same Order, in 1899 he was created Chevalier Mauriziano, and in 1906 the title of Commendatore was bestowed on him. His death removes another and almost the last of the pioneers of cable telegraphy, and his loss is deeply regretted by his colleagues and by all those with whom he was in social or business relations. W. J.

JAMES ENRIGHT died at Croydon on the 1st April, 1917, at the age of 78. He was born in Limerick and came to London when about 19 years of age to study medicine at St. Mary's Hospital. He took an intermediate M.B., but decided not to continue the study of medicine. He passed the London B.Sc. Examination, obtaining the third place in Honours in Logic and Psychology in 1875. About this period he became the Head of the Science Department of St. Mary's Training College, which position he retained till about 1898. Simultaneously for several years he carried on a large army-coaching establishment in conjunction with Mr. Basset-Hopkins. He read several papers before the Physical Society, of which he was a Fellow, and he was also the author of "Qualitative Analysis." He took out a number of patents, none of which, however, proved of any great commercial importance, and for many years he had a small consulting practice, principally in connection with inventions and research work. After the termination of his engagement at St. Mary's College he took up this class of work more seriously and became senior partner in the firm of Messrs. J. & J. S. Enright. Between 1898 and 1908, when he practically retired from professional work, the firm acted as consulting engineers to over

35 municipalities and companies principally in connection with electric light and power and tramway installation. He was elected an Associate of the Institution in 1897, an Associate Member in 1899, and a Member in 1901. J. S. E.

LIEUTENANT-COLONEL ROBERT WHITEHEAD HAMMOND was the only son of the late Robert Hammond who was for many years Treasurer of the Institution. He was born at Middlesbrough-on-Tees, in Yorkshire, in 1876, and was educated at Eton. From school he went in 1893 to Messrs. Fowler's steam plough works, at Leeds, where he worked in the shops and in the drawing office for 3 years. "Bob" Hammond had a happy way of adapting himself to circumstances, and was very popular with the workmen. He entered Faraday House in January 1897, and took Honours in the final examinations. From Faraday House he went to Messrs. Siemens' works at Woolwich, and from there into his father's office. Shortly after the battle of Colenso he enlisted in the Montgomeryshire Yeomanry. After a few months in South Africa he fell ill, like many others, with enteric fever at Bloemfontein, and was invalided home. In 1902 he was taken into partnership by his father, and was elected a Governor of Faraday House. In this year he married Madeline Beatrice, daughter of George Kent, of Highgate, a well-known lady golf-player, and devoted most of his spare time to golf. He was a scratch player with a marvellously long straight drive, and was a member of the Deal, Machrihanish, Ashdown Forest, and Limpsfield Golf Clubs. He was also Treasurer of the Engineering Golfing Society and won many trophies. Very shortly after the outbreak of the present war he enlisted in the University and Public School Brigade and, on the strength of his South African experience, was given command of a company. In the autumn of 1915 he went with his brigade to the Front. He was invalided home early in 1916, but after an operation he was well enough to resume duty and was attached to a training reserve battalion at Edinburgh. In the spring of 1917 he was at Aldershot and returned to the Front in July. He greatly distinguished himself in action on September 20th. By temperament, he was absolutely fearless. The general commanding the division wrote to him as follows:—

"I wish to place on record my appreciation of your courage on 20th September, 1917, when you rallied wavering troops of another unit, and made the position secure. Later, you went forward under heavy shell and machine-gun fire, and warned men in detached positions of an impending counter-attack, organizing the various parties for defence utterly regardless of personal danger."

On September 23rd he was made a Lieut.-Colonel and given the command of a battalion of the Royal Fusiliers. He was mortally wounded when at mess on September 28th by a chance bomb dropped from an aeroplane, and died on September 30th in a casualty clearing station. He never saw his general's letter, or knew that he had been awarded the Military Cross. He did a great deal of technical work for his father and rendered him valuable assistance in the many light railway and tramway Bills, arbitration and rating cases, in which the latter was retained as an expert. He was also responsible for the design of the electricity works and refuse destructor erected for the Rhondda Urban District Council. He took a keen interest in everything connected with the training of engineers and, until the outbreak of war, attended regularly all the Governors' meetings at Faraday House. He was a member of the Nomenclature Sub-Committee of the British Electrotechnical Committee and took the greatest interest in several mechanical engineering problems. He was elected an Associate of the Institution in 1898, an Associate Member in 1902, and a Member in 1907. He will be sadly missed by a very wide circle of friends.

"Qui ante diem periit, sed miles, sed pro patria." A. R.

JOHN HESKETH, the second son of a cadet branch of the Hesketh of Rufford, Lancashire, was born at Lytham in 1868. At the age of 14 he entered the railway telegraphic service and commenced what was to prove his hobby and life's work. Within the period that most youths take to master the Morse code he was a sufficiently skilled operator to warrant appointment as telegraphist by the British Post Office. His telegraphic services were spent in the Newcastle-on-Tyne operating room. In those early days technical colleges and classes were unknown, but the young telegraph enthusiast collected around him a few kindred spirits from amongst the Newcastle-on-Tyne telegraphists and, securing as lecturer Mr. A. W. Heaviside, then a superintending engineer in the service of the British Post Office, started what was undoubtedly the first post-office engineering class in the Tyneside district. His natural ability being speedily recognized by Heaviside, he was transferred to the engineering branch of the Post Office service. Leaving the telegraphic service for a period about the year 1892, he took up the position of Borough Electrical Engineer to the Blackpool Corporation. The service was remodelled and improved, loads adjusted and economies effected, such as won speedy recognition from the Council. In 1896 he accepted the post of Electrical Engineer to the Government of Queensland, and with characteristic energy he started to reorganize the telegraph and telephone service of that State. In 1904–5 he was deputed to visit America and Europe in the interests of the telegraphic services, and whilst in St. Louis acted as Australia's representative at the International Electrical Congress at the Exposition held there. At the conclusion of the Congress he visited the most important cities of the United States of America, Great Britain, and the Continent of Europe, investigating in each the problems of his profession, and culling with remarkable prescience such developments as were to promote the efficiencies of the Australian services. His report was printed by Order of Parliament, and the views expressed regarding the lines upon which the development of the service might be expected have been closely fulfilled. In 1906,

the year following his return from this tour of inspection and investigation, he was appointed Chief Electrical Engineer to the Commonwealth, and thereafter, as a result, notwithstanding many hindrances of both a political and financial nature, the telegraph and telephone service of the Commonwealth has kept as nearly as possible in line with the best and most economical practice in England and America. One of the first and greatest reforms urged was the abolition of the old and very unjust flat rate, and the introduction of measured service for telephone calls. Mr. Hesketh early recognized the merits of the common battery system, and one of his first acts on taking up the position of technical adviser to the Postmaster-General's Department was to prepare specifications for the introduction of this system into Australia. He inaugurated telephone development studies, without which economy in the location and lay-out of an exchange is impossible. He resuscitated the Wheatstone fast-speed system of telegraph working between the capital cities, which, though introduced into Australia many years earlier, had lain dormant, pending a proper organization of the traffic. He devoted special attention to the safe working and prevention of inductive interference between the lines of the Postmaster-General and those of electric lighting undertakers, and in 1909 acted as Chairman of the Melbourne Conference of Electrical Engineers, at which rules were drawn up for the protection of the Postmaster-General's plant, and regulating the lines of development of each class of service. In 1911–12 a further visit was paid to America, England, and the chief cities of the Continent. Rapid developments were taking place on both the telephone and telegraph sides. In the former field the "battle of the automatics" was raging, whilst in the latter the whole trend of progress was in the direction of printing telegraph systems. He recommended the early extension of automatic systems in Australia, and it is of interest to record that the first public automatic exchange was opened in Australia (Geelong) within a month or two of the opening of the first automatic exchange by the British Post Office (Epsom) His strong faith in "automatics" has been fully justified by results, and it may be stated that, having regard to the number and size of its exchanges, Australia has a greater proportion of automatics than that of any country in the world, America not excepted. Telegraphically Mr. Hesketh recommended the Creed system to handle the traffic between the Eastern and Western States, and one of his last important recommendations was to equip the inter-capital lines to the Northern States with the latest and most promising multiplex printing system. In 1915, in collaboration with two other of the principal officers of the Postmaster-General's Department, he inquired into the financial basis of the telegraph and telephone services, and, as a result, recommendations were made to alter the rates for telephone and trunk-line calls. His early opposition to single-wire telephones, his advocacy of placing telephone cables underground, his expert assistance during the conduct of the various Arbitration Court cases, and the precise statistical information collected throughout his professional career, all combined to promote efficiency and economy in the Post Office engineering services of the Commonwealth. He was elected an Associate of the Institution in 1890 and a Member in 1895. He served as local Honorary Secretary and Treasurer for Queensland from 1903 to 1906, and as Local Honorary Secretary and Treasurer for Victoria from 1906 until his death. T. H.

JAMES GRIEVE LORRAIN was born in 1852 and died on the 23rd August, 1917. The son of a physician and the grandson of a Grammar School Head Master, Mr. Lorrain started life with inherited capacity in science and literature. His engineering career commenced as a pupil of a Civil Engineer of Edinburgh, and he subsequently became a pupil of Professor Fleeming Jenkin, F.R.S. At Edinburgh University he studied two years, passing with distinction in mathematics, physics, and mechanics. University College, London, the Royal School of Mines, and lectures at the College of France in Paris, were further successive stages in his education. He held an appointment as chemist to the Oakbank Works, Midcalder, and then started in private practice as an electrical engineer in Edinburgh. When so engaged, the telephone was brought out and Mr. Lorrain was amongst the first to realize its value and afford the public practical experience of its utility. He erected some of the first telephone lines in Scotland, and in association with an American named Tracy was concerned also in the first exchanges at Manchester, Liverpool, Edinburgh, Dundee, and Belfast, as well as such distant fields as India. All these enterprises were early acquired by other companies and merged into larger organizations—the British exchanges eventually becoming "National" and the Indian exchanges "Oriental." It must be accounted a misfortune that only the enterprises were merged and Mr. Lorrain himself not taken over, for his training and experience would have been of value in the development of the telephone business. In 1881 Mr. Lorrain resumed his practice as a Consulting Engineer, this time opening an office at Westminster. At some time in the early eighties he was associated with the Kinetic Engineering Company, introducing new electrical applications including the Berthoud Borel Cable—one of the earliest makes of lead-covered cable. In 1886 he commenced the study of patent law, and after two years' assiduous application started in practice as a patent agent, to which (in addition to practising as a consulting engineer) he applied himself for the remainder of his life. Mr. Lorrain took an active part in the social side of electrical interests, as a Mason, as a Member of Council of the "Dynamicables," and as Secretary of the Twenty-Five Club. With a distinctly aristocratic appearance he held very democratic views, to which may perhaps be attributed the absence of any prefixes in the record of attendances of the Twenty-Five Club. He would sometimes tell how there was at one time in his employ a certain John Burns who subsequently acquired the suffix of M.P. and the prefix of "Right Hon." Mr. Lorrain was elected a Member of the Institution in 1879. He was also a Member of the Institution of Mechanical Engineers, a Fellow of the Royal Physical Society of Edinburgh, a Fellow of the Chartered Institute of Patent Agents, a Member of the Société

Française de Physique, a Member of the Society of Chemical Industry, and a Member of the American Institute of Electrical Engineers. His loss is deplored by a wide circle as that of an able, kindly, and cultured friend. J. E. K.

EVELYN EDWARD PORTER received his early education at St. Mark's School, Windsor, and at Sherborne School. After a two years' course at the Crystal Palace Company's School of Practical Engineering he was for a short time a premium apprentice with the Consolidated Telephone Construction and Maintenance Company, Ltd. He then took a laboratory course of sugar analysis and obtained an appointment on a sugar estate in the West Indies. In 1886 he was appointed Manager to the China and Japan Telephone Company and remained with that Company for about 11 years; during part of this period he also served as Secretary to the Shanghai Electric Light Company. In 1897 he founded the electrical contracting business of E. E. Porter and Company, which was later, in 1905, converted into a limited company, Mr Porter being appointed managing director, a position which he held until his retirement in April 1910. He then returned to England and lived at Weybridge, Surrey, where he died on the 28th April, 1917, at the age of 53. He was elected an Associate of the Institution in 1885 and a Member in 1893. W. S. D.

REUBEN MARCHANT SAYERS died on Christmas-day, 1917, from typhoid fever. He was educated at St. Paul's School, and was trained in electrical and engineering work at the City and Guilds Institute, South Kensington, of which he was a prominent student. In 1897 he joined the firm of Messrs. Clarke, Forde and Taylor as an assistant engineer, and for 20 years was associated in the important works which they have undertaken. It has been the writer's privilege to have known Mr. Sayers intimately for all those years, and it is not speaking too highly of him to say that his ability and character earned everyone's esteem, and the many letters received are eloquent testimony to the regard felt for him as an engineer and as a man who endeared himself to all with whom he came in contact in the course of his career. His first work on submarine cables was in connection with the laying of the Bermuda–Turk's Island–Jamaica cable in 1898, and in the 19 years following he led a busy life, acting as Chief Assistant and afterwards (in 1910) when he became a partner in the firm, on many cable-laying expeditions; amongst these may be mentioned the Pacific cable and the laying of the following Commercial Companies' cables: Fayal (Azores) and Canso (Nova Scotia), Weston-super-Mare and Waterville (Ireland), New York and Havana, diversion of Atlantic Cable to St. John's, N.F., extension of St. John's–Canso cable to New York, and several successful deep-sea repairing expeditions. He possessed abilities in such a marked degree and was so earnest in all he undertook that he will leave his mark on the calling he had chosen and for which he was especially fitted by sound knowledge, ability, and charm of manner. He contributed a number of papers on electrical subjects to the technical journals, and quite recently attacked the difficult problem of computing the depreciation of submarine cables, his death depriving the industry of an important paper on this subject. His services to the various cable companies for whom he has acted have been recognized in the fullest and most sympathetic way. He was not a man who courted publicity, but the amount of "spade work" that he did for his firm and their clients is known to the writer, who cannot speak too highly of one whose loss is deeply deplored by all. He joined the Institution as a Student in 1896, was elected an Associate in 1898, and was transferred to the class of Members in 1911. A. L. D.

JOHN SCUDAMORE SELLON whose death at the age of 81 took place on the 18th January, 1918, in London, was born in 1836, fifth son of Captain William Baker Sellon, R.N. At an early age he joined the well-known business house of Johnson, Matthey & Company, assayers and refiners to the Bank of England and Royal Mint, metallurgists, etc., founded by his uncle, Percival Norton Johnson, in 1822. He played a prominent part in the researches and industrial developments connected with the platinum and other groups of rarer metals, with which the name of his firm is closely associated; indeed the now numerous and important commercial applications of platinum and its allied metals may be said to be chiefly due to the initiative and efforts of himself and his co-workers George and Edward Matthey. During the concluding quarter of last century he also took an active share, both in the fields of technical discovery and industrial development, in the then new sphere of electrical engineering, and he was associated with Faure, Brush, Swan, Lane-Fox, Volckmar, and others in their early work on electric lighting and storage. He married in 1858 Fanny Maria, daughter of Captain Thomas Alexander Souter, 44th Regiment, who survives him. He was elected an Associate of the Institution in 1881 and a Member in 1885. R. P. S.

WILLIAM HENRY STONE, member of the first class of the Imperial Japanese Order of the Rising Sun and of the first class of the Imperial Japanese Order of the Sacred Treasure, Commander of the Royal Danish Order of Dannebrog, Adviser to the Japanese Telegraph Administration, died on the 3rd June, 1917, at his residence in Tokio, after a short illness. He was born on the 18th June, 1837, at Sligo, Ireland, and went to Japan in 1872 to join the Japanese Telegraphs, and remained in the telegraph service until his death, although in later years he had, owing to his very advanced age, practically retired. He was elected an Associate of the Institution in 1875 and a Member in 1887. In 1884 he was awarded the Fahie premium for a paper on "The Physiological Bearing of Electricity on Health." I. N.

SIR JOHN WOLFE WOLFE-BARRY, K.C.B., who died on the 23rd January, 1918, was elected a Member of the Institution in 1991 and served on the Council from 1902 to 1905. To the general public his name

probably suggests the brilliantly successful constructor of railways, bridges, and docks, to some members of his profession he is pre-eminently the pioneer of systematized technical education, and again to others it is as the founder of the Engineering Standards Committee that he is best known. The fact is that he rendered unrivalled service in each and all of these directions. The youngest son of the late Sir Charles Barry, R.A., architect of the Houses of Parliament and the Reform Club, Sir John Wolfe-Barry was born in London on the 7th December, 1836. After passing through King's College, London, he became a pupil of Mr. (later Sir) John Hawkshaw, with whom he was afterwards associated in the construction of the extensions of the South-Eastern Railway into Charing-cross and Cannon-street. In 1867 he started in practice on his own account, and henceforward his life was one long succession of notable engineering achievements. It is almost impossible to give a full list of the engineering undertakings with which his name is identified, but among the most notable may be mentioned the Tower Bridge, which took six years—from 1886 to 1894—to design and erect, and for which he was made Companion of the Bath; Blackfriars Railway Arched Bridge (1883–87); Kew Bridge (1898–1903); and much railway work at home and abroad, especially in India. It is, perhaps, however, as a docks engineer that the greatest calls were made upon Sir John's engineering skill, chief amongst the examples of his work in this direction being the Barry Docks and Railways, begun in 1885. Great as was his achievement in the field of constructional works, it was by no means the only direction in which he rendered valuable service to the nation. He was a frequent witness before Parliamentary Committees, and was chosen to sit on numerous Commissions. In many cases he acted as arbitrator, and was one of the three members of the Court of Arbitration in connection with the Metropolitan Water Board scheme. The subject of London traffic was one in which he always took a keen interest. In an Address as Chairman of the Council of the Society of Arts in 1898, and again in 1899, he pointed out the serious pecuniary losses caused by the congestion of the London streets and urged the desirability of forming subways. He also gave much thought and attention to the subject of engineering education and was responsible for the determination of the Institution of Civil Engineers (of which he was elected President in 1896) to establish an examination as a condition of entry to its ranks. As Chairman of the Executive Committee of the City and Guilds of London Institute, he likewise worked for the cause of engineering education in London. Before giving an account of perhaps the greatest contribution which Sir John made to the progress of the engineering industry in his tireless efforts to secure standardized manufacture, mention may be made of his activities outside his own profession, which, incredible as it may seem when one considers the immense amount of engineering work accomplished, were manifold. Up to his death he was Chairman of the House Committee of Westminster Hospital, and at different periods a member of the Senate of the University of London, a member of the Governing body of the Imperial College of Technology, a member of the Army and Navy Council, and of the Council of King's College, London, and Chairman of the Eastern and Eastern Extension and Western Telegraph Companies. He was made a Knight Commander of the Bath in 1897, held the honorary degree of LL.D. of Glasgow University, was Colonel in the Engineer and Railway Volunteer Staff Corps, and was Deputy Lieutenant of the County of London. Standardization was always very near his heart, and it was at his instance that in 1901 the Council of the Institution of Civil Engineers unanimously resolved to approve a proposal to appoint a Committee for the standardization of Rolled Sections. From this small nucleus, consisting of some half-dozen members, has been evolved the British Engineering Standards Association which now deals with every branch of engineering standardization and has some 860 members who voluntarily give their time and labours to the work. From the inception of the organization until the day of his death, Sir John filled the office of Chairman, and, as the creation of this body was so largely due to his personal foresight and enterprise, so in an equal measure has the success and development of the movement been a result of his commanding ability for leadership. He always insisted on the community of interest of producer and user, and the advantage to be gained by coming together on neutral ground and discussing difficult problems in that spirit of mutual compromise and forbearance which characterized his chairmanship on all occasions. So virile was his intellect, so judicial his mind, and so broad his conception of things generally, that his ruling on any question was sure to be absolutely equitable and, even on those occasions when his view was not entirely shared by his colleagues, it was ultimately invariably found and acknowledged to be the correct one. Hence the absolute confidence reposed in him by all with whom he had to do. The last occasion on which he presided at a meeting of the Main Committee was in November 1917, when Mr. H. M. Hobart, the American delegate to an Anglo-American Electrical Conference, was present at his special invitation. A few weeks previously Sir John had addressed a speech of welcome to Mr. Hobart, in which, in making allusion to the alliance of the two English-speaking nations in the fight for freedom, he said:—

"It is a matter of the most profound gratification that the two great Governments of the Anglo-Saxon race are now marching side by side in the great endeavour to forward the interests of humanity, having both of them the same ideals and looking forward to a peace which shall guarantee those ideals and aspirations to the world now so sorely afflicted by war and its attendant miseries."

It seems peculiarly fitting that the last recorded words of this marvellously progressive mind should be concerned with an event of such vital moment to the onward march of humanity as the entry of the United States into the great struggle for Liberty. C. Le M.

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EXPLANATION OF ABBREVIATIONS.

(P) indicates a reference to the general title or subject of a paper or address.

(p) indicates a reference to a subject dealt with in a paper or address of which the title is not quoted.

(D) indicates a reference to a discussion upon a paper or address of which the general title or subject is quoted.

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THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 1. Dec. 1917. INSTITUTION NOTES. [ISSUED WITH No. 269 OF THE JOURNAL.]

Forthcoming Meetings.

ORDINARY MEETINGS OF THE INSTITUTION.

Date.	*Author and Title of Paper.*
1917.	
6 Dec.	W. A. Gillott: "Electrical Cooking as applied to Large Kitchens."
13 Dec.	L. B. Atkinson. "The 'Pros and Cons' of the Metric System."
	A. J. Stubbs: "A Case for the Adoption of the Metric System (and Decimal Coinage) by Great Britain."
1918.	
10 Jan.	C. M. Jacobs: "Electrical Signalling and Control on Railways."

MEETINGS OF LOCAL SECTIONS.

Date.	*Place of Meeting.*	*Author and Title of Paper.*
1917.		
5 Dec.	Birmingham	T. M. Hunter: "Gas Firing Boilers."
11 Dec.	Glasgow	T. M. Hunter: "Gas Firing Boilers."
11 Dec.	Manchester	W. A. Gillott: "Electrical Cooking as applied to Large Kitchens."
14 Dec.	Dublin	T. M. Hunter: "Gas Firing Boilers."
18 Dec.	Leeds	W. A. Gillott: "Electrical Cooking as applied to Large Kitchens."
18 Dec.	Newcastle	Visit by the President.
1918.		
8 Jan.	Edinburgh	W. A. Gillott: "Electrical Cooking as applied to Large Kitchens."
— Jan.	Birmingham	(To be announced later.)
11 Jan.	Dublin	Lecture by Mr. J. P. Tierney, and visit to the University College.
14 Jan.	Newcastle	W. A. Gillott: "Electrical Cooking as applied to Large Kitchens."
15 Jan.	Manchester	C. M. Jacobs: "Electrical Signalling and Control on Railways."
29 Jan.	Manchester	(To be announced later.)

Election of an Honorary Member.

The Council have elected Professor Augusto Righi, of Bologna University, to be an Honorary Member of the Institution.

Research.

The Committee of the Privy Council for Scientific and Industrial Research have made a further grant to the Institution of £670 towards the cost of the research into the properties of insulating oils.

Silvanus Thompson Memorial.

An Inaugural Address delivered by the late Dr. Silvanus Thompson to first-year students of the Finsbury Technical College has been published in pamphlet form, with an introductory memoir by an old student. The pamphlet, which comprises 32 pages, also contains a portrait of Dr. Thompson and a half-tone reproduction of one of his water-colour drawings.

Copies can be obtained by sending a remittance of 2s. 2d. (which includes postage) to The Secretary, Thompson Memorial Committee, Finsbury Technical College, Leonard Street, City Road, London, E.C.

The profits from the sale of the pamphlet will be presented to the Thompson Memorial Fund of the Old Students' Association.

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Palmer, 2nd Lieut. W. S. H.	Royal Flying Corps	Student
Trouton Captain D. G.	Royal Field Artillery	Student

Died of Wounds.

Cunliffe Captain J. G., M.C.	Manchester Regt.	Associate Member
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Died.

Bowker Major R. B.	Royal Engineers	Associate Member
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Ewer, Lieut.-Col. G. G.	Essex Regt.	Associate Member

"He displayed great ability and resource under fire, organizing the ammunition and water supply of his brigade and supervising the collection of wounded and the disposal of prisoners. He performed invaluable services, and the success of the operations was largely due to his efforts." —*London Gazette*, 16 August, 1917.

Military Cross.

Atkins, Actg.-Capt. A. H.	Royal Garrison Artillery	Associate Member

"When in command of a sound-ranging section, and under heavy howitzer fire, he showed the greatest courage in digging out and attending to men who had been buried by a shell in one of the shelters. Although much bruised and shaken himself, he personally superintended all the work, and his coolness and determination had great effect on the men of his detachment, who were much shaken by the heavy losses. He has at all times shown himself to be a fearless and capable officer, constantly accompanying repairing parties into the most dangerous areas." —*London Gazette*, 16 August, 1917.

* See vol. 54, pp. 64, 447, and 675, and vol. 55, pp. 55, 193, 325, and 537.

† See vol. 54, pp. 306, 518, and 674, and vol. 55, pp. 56, 193, 325, and 537.

Barlow, Flight-Com. L. M. — Royal Flying Corps — Student

"For conspicuous gallantry and devotion to duty when engaged in aerial combats. He has set a very fine example of courage and dash in attacking and destroying hostile machines. He also attacked and stopped a goods train, silenced a machine gun on an enemy aerodrome, and dispersed troops on the roads from a very low altitude."—*London Gazette*, 25 August, 1917.

Cunliffe, Captain J. G. — Manchester Regt. — Associate Member

"When commanding a company in the front line he opened rapid fire upon a hostile patrol, which was attempting to enter the trench, and then led his party over the parapet in full view of the enemy, by his personal courage and fearless example dispersing them with loss and taking several prisoners."—*London Gazette*, 25 August, 1917.

Lee, Captain J. H. — Yorkshire Regt. — Student

"He pushed forward with his company and held a position against repeated hostile counter attacks, holding it for 48 hours, although his force was reduced to five men and one Lewis gun. He sent back valuable and reassuring reports to his Commanding Officer, and he set a splendid example of coolness and ability under the most trying circumstances."—*London Gazette* 25 August, 1917.

Newton, Captain R.S. — Lancashire Fusiliers, attd. R.E. — Associate Member

Peter, Captain L. H. — Royal Flying Corps — Student

"When leading a reconnaissance his formation was attacked by hostile scouts. He kept his machines together and carried out a successful photographic reconnaissance despite a strong attack. To his leadership and initiative was largely due the success of the patrol."—*London Gazette*, 18 July, 1917.

Redgrave, Lieutenant H. C. — Royal Engineers — Graduate

Riley, 2nd Lieut. T. S. — Army Service Corps — Student

Robertson, 2nd Lieut. H. — Royal Field Artillery — Associate Member

"As forward observing officer during an infantry attack he showed the greatest skill in establishing and maintaining the artillery communications. He also displayed great gallantry in attending to the wounded, and personally attacked and dispersed a considerable party of the enemy who were about to attack his heavily-laden signallers. His conduct throughout was invaluable towards promoting the success of this operation."—*London Gazette*, 16 August, 1917.

Sim, Actg. Capt. N. S. — Cameron Highlanders — Associate Member

"He led his men forward to assist the advance on the right. He exposed himself fearlessly in forming a strong point, which he held all day. Throughout he set a splendid example under most trying conditions."—*London Gazette*, 18 July, 1917.

Taylor, Actg.-Maj. G. S. — Royal Engineers — Associate Member

"For conspicuous gallantry and devotion to duty on several occasions. One notable instance was when he was in charge of a large 'labour company' working party engaged in constructing light railways. They were subjected to heavy fire. By his coolness and presence of mind they were conducted out of the shell area without any casualties, although the bombardment was intense. He subsequently displayed very great gallantry in personally digging out men who had been buried by shell fire, and in cutting trenches across No Man's Land under very trying conditions, in which he set a very fine example of energy and courage under shell fire."—*London Gazette*, 17 September, 1917.

Bar to Military Cross (twice).

Barlow, Flight-Com. L. M. — Royal Flying Corps — Student

Military Medal.

Mackie, Lance-Corpl. A. P. — New Zealand Engineers — Student

Legion of Honour (Croix de Chevalier).

Cormack, Colonel J. D., C.M.G. — General List — Member

Croix de Guerre.

Gripper, Driver L. A. — Friends' Ambulance Unit — Student

Mentioned in Despatches.

Alexander, Major R. D. T., D.S.O. — London Regt. — Associate Member

Newton, Captain R. S., M.C. — Lancashire Fusiliers — Associate Member

Pitkeathly, Major J. S., C.V.O. — Special List — Associate Member

Mentioned.

Sadd Captain J. A — Special List — Associate Member

Sellon, Captain E. M. — Canadian Infantry — Member

Members on Military Service.

THIRTEENTH LIST.*)

MEMBER.

Name	*Corps, etc.*	*Rank.*
Taylor, A. M.	Staff (D.F.W.)	Captain

ASSOCIATE MEMBERS.

Bissett, F. W.	Royal Engineers	2nd Lieut
Constable, E. J.	Canadian Engineers	Corporal
Corringham, G.H.	Chinese Labour Corps	2nd Lieut.
Greenhalgh, E.	R.N.V.R.	Lieutenant
Hay, P. G.	Royal Engineers	2nd Lieut.
Jackson, E. W.	St. John Ambulance Brigade	Ambulance Officer
Morris, A. T.	Aeronautical Inspection Directorate	Chief Examiner
Rayner, A. J	Indian Defence Force	Private
Savill, A. G.	R.N.V.R.	Lieutenant

GRADUATES.

Cheal, A. E. E.	Royal Flying Corps	2nd Lieut.
Collett, E. P.	Royal Engineers	2nd Lieut.

STUDENTS.

Barlow, H. E. M.	Staff (W.T.)	Sub-Lieut.
Barraclough, G.H.	R.N.V.R.	Sub-Lieut.
Cooper H. R.	R.N.V.R.	Midshipman
Cunningham, J.A.	Union of South Africa Defence Force	Private
Housden, F. R.	Royal Engineers	Sapper
Humm, R. W.	Royal Navy	Wireman
Mahon, B. E.	Royal Engineers	Cadet
Reily, P. A.	Royal Engineers	Sapper
Steers, H. D.	Royal Engineers	Major

INSTITUTION STAFF.

Rayner, A. E.	Army Service Corps	Private

* See vol. 53, pp. 199, 326, 388, and 857; vol. 54, pp. 121, 403, 518, and 675; and vol. 55, pp. 57, 194, 326, and 538.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 2. JAN. 1918. INSTITUTION NOTES. [ISSUED WITH No. 270 OF THE JOURNAL.]

Forthcoming Meetings.

ORDINARY MEETINGS OF THE INSTITUTION.

Date. 1918.	*Author and Title of Paper.*
10 Jan.	C. M. JACOBS: "Electrical Signalling and Control on Railways."
24 Jan.	F. G. C. BALDWIN: "Telephone Exchange Transfers and their Organization."
7 Feb.	Professor MAGNUS MACLEAN: "Kelvin as a Teacher" (Ninth Kelvin Lecture).
21 Feb.	C. C. GARRARD: "Switchgear Standardization."

LOCAL SECTIONS.

Date. 1918.	*Place of Meeting.*	*Author and Title of Paper.*
8 Jan.	Edinburgh	W. A. GILLOTT: "Electrical Cooking as applied to Large Kitchens."
11 Jan.	Dublin	Lecture by Mr. J. P. TIERNEY, and visit to the University College.
14 Jan.	Newcastle	W. A. GILLOTT: "Electrical Cooking as applied to Large Kitchens."
15 Jan.	Manchester	C. M. JACOBS: "Electrical Signalling and Control on Railways."
16 Jan.	Birmingham	Informal Discussion.
29 Jan.	Manchester	F. G. C. BALDWIN: "Telephone Exchange Transfers and their Organization."
8 Feb.	Dublin	(To be announced later.)
11 Feb.	Newcastle	F. G. C. BALDWIN: "Telephone Exchange Transfers and their Organization."
12 Feb.	Glasgow	Visit by the PRESIDENT (Mr. C. H. Wordingham). Professor MAGNUS MACLEAN: "Kelvin as a Teacher" (Ninth Kelvin Lecture).
12 Feb.	Leeds	E. C. MCKINNON: "Large Batteries for Power Purposes."
12 Feb.	Manchester	Professor E. W. MARCHANT: "Some Transient Phenomena in Electrical Supply Systems."
20 Feb.	Birmingham	Professor MAGNUS MACLEAN: "Kelvin as a Teacher" (Ninth Kelvin Lecture).
26 Feb.	Manchester	E. C. MCKINNON: "Large Batteries for Power Purposes."

STUDENTS' SECTION.

Date. 1918.	*Place and Time of Meeting.*	*Author and Title of Paper.*
22 Jan.	Finsbury Technical College (7 p.m.)	R. L. SMITH-ROSE: "The Evolution of the Thermionic Valve."
8 Feb.	Faraday House (7 p.m.)	R. W. CORKLING: "Magnetos."

The Late Mr. W. Duddell.

At the meeting of the Manchester Local Section on the 13th November, 1917, the following resolution was passed:—

"That this meeting of the Manchester Local Section of the Institution of Electrical Engineers expresses its sincere sympathy with the mother and family of the late Mr. W. Duddell, and places on record its appreciation of the distinguished services which he has rendered to Electrical Science, to the Electrical Engineering Industry, and to the Institution of which he was but recently President."

In proposing the above resolution, Professor E. W. MARCHANT said:

"It is over 20 years ago since I first met Duddell as a student at the Central Technical College, and I hope it will not be considered inappropriate if I give one or two personal recollections of him in the early days. It was my great good fortune to become associated with him in the work he was doing on the alternating-current arc: he had developed a point-by-point method of plotting wave-forms, and we had taken a great number of records in that way. Their delineation, however, by a special instrument that would show them instantaneously was being worked at in the laboratory. Duddell first made a bifilar oscillograph with flat strips in his workshop at home and brought it along to test. We found the damping ineffective, so he constructed an oil bath in which the strips vibrated, and in the end he made separate channels for each strip, a task requiring the greatest refinement and skill in workmanship. It is recorded that when he made his first high-frequency oscillograph and showed the drawings to a firm of instrument makers, they said that the instrument could not be made, whereupon he showed them the one he had himself constructed. He was an extraordinary instrument maker, and had it not been for this, the oscillograph could never have been produced. The development of the apparatus that was subsequently shown to the Institution was a wonderful education for a student, and an example, which I shall never forget, of the thoroughness with which he tackled every problem that was set before him. With it all, he showed a boyish enthusiasm in his work which he never lost throughout his life. He talked about his experiments with such interest and charm that his audience was carried away. As Mr. Mordey said when

he opened the adjourned discussion on the paper on 'Alternate Current Arcs,' 'his heart was fuller than his head,' and this was the feeling of most of his audience at the end of one of his lectures. This quality was evident in all the papers that he read before the Institution, and it was never more marked than in the brilliant address which he gave in 1914 at the beginning of his second year of office as President. All those who know the inner working will appreciate the value of his services on Institution Committees. He was an admirable chairman, punctual and regular in his attendance, and he always kept the work of the committee well in hand. He performed invaluable services in connection with the Library and Museum; the efficiency of the Library is very largely due to his untiring energy. But he was not known only as a Member of the Institution. He was a distinguished Fellow of the Royal Society, and was awarded the Hughes Medal in 1912. He was President of the Commission Internationale de Télégraphie Sans Fil, a Past-President of the Röntgen Society, and for many years Treasurer of the Physical Society.

"He has gone, but he has left behind him a record of which any man might be proud. In the all too short time he spent at his profession, he did, I venture to say, as much for the progress of Electrical Science as any man of his time. He leaves behind him a great record of achievement; but what I think is a greater thing than that, he leaves to his friends the memory of an enthusiast for science, of a personality extraordinarily modest, of a frank and open nature, and of a loyal and unswerving friend."

Portraits of Scientists.

The Council have purchased, on behalf of the Institution, the late Mr. Duddell's collection of portraits of scientists. The collection comprised 66 portraits, amongst which are those of Ampère, Arago, Bernoulli, Boyle, Brewster, Copernicus, d'Alembert, Davy, Descartes, Euler, Faraday, Franklin, Galileo, Gay-Lussac, Gresham, Hamilton, Keppler, Kirchhoff, Lagrange, Laplace, Leibnitz, Le Verrier, Malus, Napier, Newton, Oersted, Ohm, Pascal, Rumford, Tartaglia, Tycho Brahe, Volta, Wheatstone, Young.

Employment Register.

The Council are arranging, in co-operation with the Ministry of Labour, for the preparation of an Employment Register of members of the Institution serving in His Majesty's Forces.

Board of Scientific Societies.

A contribution of £50 has been made by the Institution towards the expenses of the Board of Scientific Societies during the year 1918.

Non-Ferrous Metals Bill.

The Council have passed the following Resolution, which has been forwarded to the President of the Board of Trade:—

"That the Council of the Institution of Electrical Engineers welcomes the Non-Ferrous Metals Bill, approves its principles, and congratulates the President of the Board of Trade on its introduction. The Council, representing an Institution whose members are interested so widely in the supply of non-ferrous metals, unanimously supports this measure designed to keep the control of the supply of these essential metals in British hands."

Greetings Card to Members on Military Service.

A greetings card has been sent on behalf of the Council and members of the Institution to members on active service.

Newcastle Local Section.

The President (Mr. C. H. Wordingham), accompanied by the Secretary, visited the Newcastle Local Section on Tuesday, 18th December, 1917. He was received by Mr. A. H. Marshall, Chairman of the Local Section, and afterwards delivered an address to the members. In the course of this address, which dealt mainly with the work of the Institution, the President referred to the desirability of obtaining a Royal Charter, research, the establishment of an Electrical Proving House, and the improvement of engineering education. A vote of thanks to the President for his address, proposed by Mr. H. W. Clothier, and seconded by Captain A. P. Pyne, was carried with acclamation.

Engineering Textbooks for British Prisoners of War.

A further appeal (see *Journal I.E.E.*, 1916, vol. 54, p. 676) for textbooks and financial assistance has been made by the Committee of the British Prisoners of War Book Scheme (Educational). The objects of the Scheme are stated by the Committee to be as follows:—

"To save British prisoners of war interned in enemy and neutral countries from mental deterioration, and to assist them to redeem the time spent in captivity (1) by providing them with books for study purposes; (2) by securing recognition from university and other examin-

ing bodies for their studies during internment ; (3) by helping them the better to fight the battle of life at the close of the war by enabling them now to employ usefully their enforced leisure and to improve their qualifications."

The statistics for the first nine months of the year 1917 show that 6,500 requests for books were received and 43,700 educational books were dispatched to the camps in enemy and neutral countries. At the present time books on the following engineering subjects are required :

Alternating Currents ;
Dynamos ;
Electric Fittings ;
Electric Lifts and Cranes ;
Electric Tramcar Driving ;
Electric Wiring ;
General Electricity ;
Management of Dynamos ;
Motors ;
Small Dynamos and Engines ;
Switchboards ;
Switches and Switchgear ;
Balancing of Engines ;
Boiler Survey ;
Engine Survey ;
Gas, Petrol, and Oil Engines ;
Heat Efficiency of Steam Boilers ;
Semi-Diesel Oil Engines ;
Steam Boilers ;
Steam Engines and Turbines ;
Theory of Heat Engines ;
Weighing-Machine Fitting ;
Construction of Levers and Go-through Lace Machines ;
Factory Engineering ;
Civil Engineering ;
Metallurgy of Iron and Steel ;
Millwright ;
Theoretical, Applied, and Experimental Mechanics ;
Modern Workshop Practice ;
Hydraulics ;
Sanitary Engineering ;
Oxy-acetylene Welding ;
Automatic Fire Extinction ;
Heating and Ventilation ;
Mechanical Engineering ;
Bridge Stresses ;
Gas Fitting ;
History of the Steam Engine ;
Modern Buildings ;
Design of Steel Bridges ;
Strength of Materials ;
Automatic Tools ;
Brass Moulding ;
Testing of Materials of Construction ;
Plumbing ;
Refrigerating Machinery ;
Concrete ;
Winding Engine Driving ;
Structural Engineering ;
Iron Drilling ;
Turning ;
Smithing, Tool Sharpening, etc. ;
Stone Quarrying ;
Pattern Making ;
Air Brakes ;
Gas Producers ;
Orders of Architecture ;
Specifications.

Offers to supply any books should be sent, with full particulars as to author, edition, date of publication, etc., to A. T. Davies, Esq., C.B., Victoria and Albert Museum, South Kensington, S.W. 7, and all communications should bear the words " Prisoners of War " in the left-hand top corner. On receipt of the offer, an intimation will be sent as to which volumes are acceptable.

The present rate of expenditure (five-sixths of which is represented by purchases of books) is £250 per month, and donations are earnestly requested.

An account of the work of the Scheme has been published in two booklets entitled " Student Captives " (Nos. I and II), copies of which may be obtained on application to Mr. A. T. Davies at the above address.

Representatives of The Institution on Other Bodies.

The following is a list of representatives of the Institution on other Bodies, and the dates on which they were appointed.

Corrosion Committee of the Institute of Metals :
Mr. J. S. Highfield (4 Oct., 1917).
Electrical Research Committee :
Mr. C. C. Paterson (4 Oct., 1917).
Mr. C. P. Sparks (4 Oct., 1917).
Mr. C. H. Wordingham (4 Oct., 1917).
Engineering Standards Committee (Main Committee) :
Col. R. E. Crompton (2 April, 1914).
Sir John Snell (2 April, 1914).
Mr. C. P. Sparks (2 April, 1914).
Ditto (Sectional Electrical Committee) :
Mr. F. Gill (21 May, 1914).
Mr. J. S. Highfield (21 May, 1914).
Mr. R. T. Smith (21 May, 1914).
Mr. C. H. Wordingham (18 Nov., 1915).
(One vacancy).
Ditto (Sectional Committee on British Standards in Colonial and Foreign Trade) :
Mr. C. P. Sparks (26 Oct., 1916).
Ditto (Sectional Committee on Machine Parts and their Gauging and Nomenclature) :
Mr. J. H. Rider (8 Feb., 1917).
Engineering Training, Committee on :
Mr. C. H. Wordingham (22 Nov., 1917).
Imperial College of Science and Technology, Governing Body :
(Vacant).
International Illumination Committee, British National Committee :
Mr. F. Bailey (27 Nov., 1913).
Mr. K. Edgcumbe (27 Nov., 1913).
Mr. H. T. Harrison (27 Nov., 1913).
Prof. J. T. MacGregor-Morris (27 Nov., 1913).
Prof. W. C. Clinton (13 Dec., 1917).
Metalliferous Mining (Cornwall), School of, Governing Body :
Mr. C. P. Sparks (23 Jan., 1913).
Ministry of Labour, Trade Advisory Committee for the Electrical Industry (Disabled Sailors and Soldiers) :
Mr. C. P. Sparks (4 Oct., 1917).
Munitions Inventions Department (Nitrogen Products Committee) :
Sir John Snell (12 Oct., 1916).
National Physical Laboratory, General Board :
Sir John Snell (21 May, 1914).
Mr. R. T. Smith (26 Nov., 1914).
Scientific and Industrial Research, Engineering Committee of Advisory Council for :
Mr. J. S. Highfield (9 March, 1916).
Scientific Societies, Conjoint Board of :
Sir John Snell (29 June, 1916).
Mr. C. P. Sparks (29 June, 1916).
Ditto, Education Committee :
Dr. A. Russell (12 Oct., 1916).
Technical Societies of Canada, Joint Committee :
Mr. S. L. B. Lines (8 March, 1917).

Promotions, Transfers, etc., of Members on Military Service.

(Ninth List.*)

MEMBERS.

Name.	*Corps, etc.*	*Rank.*
Alkin, R. L.	Royal Engineers	Captain
Andrews G. L.	Royal Garrison Artillery	Actg. Maj.
Barber, C.	Royal Flying Corps	Major
Caldwell, J.	Royal Engineers	Captain
Coombs, A. M.	Royal Flying Corps	2nd Lieut
Covernton, R. H., M.C.	South African Engineers	Actg. Capt.
Erskine-Murray, J.	R.N.V.R.	Lieut.-Com.
Roose, F. O. J.	Royal Garrison Artillery	Captain
Sellon, E. M.	Canadian Infantry	Captain
Vyvyan, R. N.	Royal Flying Corps	Captain
Wadsworth, T.	Royal Engineers	Staff-Sergt.
White, B. G.	Royal Engineers	Major

ASSOCIATE MEMBERS.

Alty J. N	General List	Lieutenant
Angers, A	South Lancashire Regt	Captain
Ash, H. D.	Lancers	Lieutenant
Atkins, A. H., M.C.	Royal Garrison Artillery	Actg. Capt.
Bennett, E. J. L.	Royal Field Artillery	Actg. Capt.
Bland, R. W. H. M.	General List	Captain
Boxall, G. F.	Royal Engineers	Actg. Capt.
Brandreth, F. H.	Essex Regt.	Lieutenant
Brazier, C. C. H.	Royal Engineers	Lieutenant
Bullock M. A.	Army Ordnance Department	Captain
Burge W. S.	Royal Engineers	Actg. Capt.
Coghlan, J.	Australian Field Engineers	Captain
Connan, J. C.	Army Ordnance Department	Actg. Capt.
Coxon, J.	Royal Engineers	Captain
Danson, J. R.	London Regiment	Regtl. Sergt. Maj.
Davies, F. H.	Army Ordnance Department	Actg. Capt
Dillon. T. F.	Royal Engineers	Lieutenant
Edmonds, C. H. W.	Royal Eng neers	Actg. Major
Ewer, G. G., D.S.O.	Essex Regt.	Lieut.-Col.
Fleming, E. W.	Royal Scots Regt.	2nd Lieut.
Fruhe-Sutcliffe, R.	Royal Engineers	Actg. Maj.
Fuller W. P.	Royal Engineers	2nd Lieut.
Golden, W. T.	R.N.V.R.	Lieutenant
Griggs, J. W.	R.N.V.R.	Lieutenant
Hammersley-Heenan, J.	R.N.V.R.	Lieutenant
Harrison, H. M.	Royal Engineers	2nd Lieut.
Hasdell, J. S.	Royal Flying Corps	1st-Class Air Mechanic
Henrici, E. O.	Royal Engineers	Major
Herron, G. F.	R.N.V.R.	Lieut -Com.
Hird, C. H.	Royal Engineers	Cadet
Hough, J. S.	Oundle School O.T.C.	Lieutenant
Hutton, J. C.	Officers' Cadet Battalion	Cadet
Keer, R. K.	London Electrical Engineers R.E.	Lance-Corpl.
Kinder, H. F. A.	Royal Engineers	Lieutenant
Knox. G. S.	Royal Engineers	Actg. Lieut.-Col.
Lawson, F. A.	Cheshire Regt.	2nd Lieut.
Lever, G. G.	Royal Flying Corps	Lieutenant

* See *Journal I.E.E.*, vol. 54, pp. 307, 404, 579, and 675, and vol. 55, pp. 59, 195, 327, and 539.

ASSOCIATE MEMBERS—*continued.*

Name.	*Corps, etc.*	*Rank.*
Lewenz, H. I.	Staff for R.E. Services	Captain
Long, R. F., M.C.	Royal Field Artillery	Captain
Manners-Smith, J. A.	Royal Flying Corps	Lieutenant
Milnes, G. C.	Royal Lancaster Regt.	Captain
Mousley, J. H., D.S.O.	Royal Engineers	Lieut.-Col.
Newton, R. S., M.C.	Lancashire Fusiliers attd. R.E.	Captain
Partridge, T. G.	Indian Army Reserve of Officers	2nd Lieut.
Podmore, A., M.C.	Royal Engineers	Lieutenant
Price, W. F.	Royal Engineers	Major
Restler, J. D. K.	R.N.V.R.	Lieut.-Com.
Routledge, L. G. F.	Royal Engineers	2nd Lieut.
Sargent, G. H.	Machine Gun Corps	Captain
Sim, N. S.	Cameron Highlanders	Actg. Capt.
Smith, W. B.	Royal Flying Corps	Sergeant
Smyth, A. H.	Army Ordnance Department	Captain
Stancombe, T. R.	Army Ordnance Department	Actg. Capt.
Stevens, E. J.	Royal Artillery	Major
Taylor, G. S. M.C.	Royal Engineers	Actg. Maj.
Thrupp, F. E. M.	Territorial Force Reserve	Lieutenant
Timmis, A. C.	Royal Engineers	Actg. Capt.
Troughton, J. A.	London Electrical Engineers, R.E.	2nd Corpl.

ASSOCIATES.

Drummond, H. H. J. W.	T.F. Reserve	Brig.-Gen.
Simpson, L. S., D.S.O.	Royal Engineers	Lieut.-Col.

GRADUATES.

Campbell, Sir J. A. C., Bart.	Yeomanry	Captain
Gibbins, J.	Hampshire (Fortress) R.E.	2nd Lieut.
Heymerdingner, F. G.	London Electrical Engineers R.E.	2nd Corpl.
McClay, J. H.	Army Service Corps	Corporal
Medforth, G. T.	Royal Engineers	Cadet
Platt, F. C.	Royal Engineers	Actg. Sergt.
Rowell J. P.	Royal Flying Corps	Lieutenant
Sparks, C. H.	Royal Flying Corps	Captain
Wood, A. N. G.	West Yorkshire Regt.	Lieutenant

STUDENTS.

Barlow, L. M., M.C.	Royal Flying Corps	Flight-Com.
Barnard L. E	Bedfordshire Regt.	Lieutenant
Chalmers, J. W. P.	Royal Engineers	Captain
Charley, R. M.	Royal Flying Corps	Lieutenant
Cripps, C. B.	London Electrical Engineers, R.E.	Corporal
Davies, G. F.	Royal Engineers	Cadet
Debley, W. J. F.	Yeomanry	Corporal
Denison, H. A., M.C.	King's Royal Rifles	Captain
Easter, C. E.	London Electrical Engineers, R.E.	Lance-Corpl.
Foster, H. H.	Royal Engineers	Actg. Corpl.
Gordon, E. A.	Royal Engineers	Corporal
Griffith, J. E.	Royal Field Artillery	Lieutenant
Haigh, G.	Royal Engineers	Corporal
Hall, W. N.	Royal Engineers	Cadet
Harris, L. G.	Manchester Regt.	Lieutenant

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 3. Feb. 1918. INSTITUTION NOTES. [ISSUED WITH No 271 OF THE JOURNAL.]

Forthcoming Meetings.

ORDINARY MEETINGS OF THE INSTITUTION.

Date.	*Author and Title of Paper.*
1918.	
7 Feb.	Professor MAGNUS MACLEAN: "Kelvin as a Teacher" (Ninth Kelvin Lecture).
21 Feb.	C. C. GARRARD: "Switchgear Standardization."
7 Mar.	E. B. WEDMORE: "The Control of Large Amounts of Power."
21 Mar.	S. F. BARCLAY: "The Mechanical Design and Specification of the Turbo-Alternator Rotor."

LOCAL SECTIONS.

Date.	*Place of Meeting.*	*Author and Title of Paper.*
1918.		
4 Feb.	Middlesbro'	T. M. HUNTER: "Gas Firing Boilers."
11 Feb.	Newcastle	F. G. C. BALDWIN: "Telephone Exchange Transfers and their Organization."
12 Feb.	Glasgow	Visit by the PRESIDENT (Mr. C. H. Wordingham). Professor MAGNUS MACLEAN: "Kelvin as a Teacher" (Ninth Kelvin Lecture).
12 Feb.	Leeds	E. C. MCKINNON: "Large Batteries for Power Purposes."
12 Feb.	Manchester	Professor E. W. MARCHANT: "Some Transient Phenomena in Electrical Supply Systems."
20 Feb.	Birmingham	Professor MAGNUS MACLEAN: "Kelvin as a Teacher" (Ninth Kelvin Lecture).
22 Feb.	Dublin	J. F. CROWLEY: "Educational and Industrial Unrest."
26 Feb.	Manchester	E. C. MCKINNON: "Large Batteries for Power Purposes."
8 Mar.	Dublin	(To be announced later.)
11 Mar.	Bristol	Annual General Meeting. E. B. WEDMORE: "The Control of Large Amounts of Power."
11 Mar.	Newcastle	(To be announced later.)
12 Mar.	Leeds	S. F. BARCLAY: "The Mechanical Design and Specification of the Turbo-Alternator Rotor."
12 Mar.	Edinburgh	C. M. JACOBS: "Electrical Signalling and Control on Railways."
12 Mar.	Manchester	E. B. WEDMORE: "The Control of Large Amounts of Power."
20 Mar.	Birmingham	C. C. GARRARD: "Switchgear Standardization."
26 Mar.	Manchester	S. F. BARCLAY: "The Mechanical Design and Specification of the Turbo-Alternator Rotor."

STUDENTS' SECTION.

Date.	*Place of Meeting.*	*Author and Title of Paper.*
1918.		
28 Feb.	Northampton Polytechnic Institute (7 p.m.)	R. GATES: "The Testing of Pyrometers."

Benevolent Fund.

Mr. C. P. Sparks, Past President, has been appointed by the Council to be a member of the Committee of Management of the Benevolent Fund, in place of the late Mr. W. Duddell.

Imperial College of Science and Technology.

Mr. C. H. Wordingham, President, has been appointed to be the representative of the Institution on the Governing Body of the above College, in place of the late Mr. W. Duddell.

Research.

The Committee of the Privy Council for Scientific and Industrial Research have made a supplementary grant of £87 10s. to the Institution for the Research on the Heating of Buried Cables.

Special General Meeting of 29th November, 1917.

On the 29th November, 1917, a Special General Meeting of the Corporate Members and Associates was held for the purpose of considering and deciding upon the question of the expulsion of a Member from membership of the Institution. At such meeting it was decided by a majority of the members who attended the meeting to refer the matter back to the Council.

The Council are now advised that as they had already investigated and taken the matter into consideration as provided by the Articles of Association they have not the power to give effect to the above decision and they are accordingly unable to take action upon it.

Address to the Students' Section.

Sir Oliver J. Lodge, F.R.S., delivered an Address on "Astronomical Consequences of the Electrical Theory of Matter" to the Students' Section on the 23rd November, 1917.

A report of the Address will be found in the issue of *Nature* for the 17th January, 1918 (vol. 100, p. 395).

Engineering Association of New South Wales.

The above Association has kindly extended all the privileges of full membership to any members of the Institution who may at any time be visiting Sydney.

Great Northern Central Hospital.

The Secretary has been asked to give publicity to the following :—

"The Committee of the Great Northern Central Hospital, Holloway, N., are anxious to receive applications for the position of Honorary Consulting Electrical Engineer, which has recently been created at that institution. The Hospital is the largest general hospital in North London, and its activities cover an area extending from King's Cross to Barnet. It contains 405 beds, 270 being at the present time used for wounded soldiers."

Lectures to Canadians at the Front.

Arrangements are being made by the Canadian War Contingent Association for courses of instruction in various subjects to men on military service. Such courses will be given in conjunction with the ordinary military training, the object aimed at being as follows :—

(1) To give the men a change of occupation and interest.
(2) To improve their knowledge of subjects which may be of use to them on their return to civil life.
(3) To give them a wide view of historical, social, and economic problems, so as to assist them in the part they will have to take in the future of the country.

During active operations the instruction will be restricted to lectures, but at the end of hostilities, when there may be a period of perhaps some months before the men can be returned home, it is proposed to form classes in which the men would be prepared for their return to civil life. For the present the proposed subjects for lectures are :—Imperial Geography ; Imperial History ; Forestry ; Mining in various branches, within the British Empire ; Farming (Cattle, Wheat, Dairy, Fruit, Poultry) ; Engineering ; Shorthand ; Accountancy and Book-keeping ; Aeronautics.

Members of the Institution willing to deliver lectures on any of these subjects are requested to communicate in the first place with J. G. Colmer, Esq., 123 Victoria-street, London, S.W. 1, who will also give information as to the payment of out-of-pocket expenses incurred by lecturers.

Proposed Informal Dinners after Institution Meetings.

At the meeting of the Institution on the 10th January, 1918, the President said :—

"In my Inaugural Address in November last I suggested that it might promote good fellowship among the members of the Institution if arrangements could be made for an inexpensive and informal dinner to take place after each meeting. I have caused inquiries to be made, and I find that under existing conditions it is a matter of supreme difficulty to arrange anything of the kind. None of the leading hotels or restaurants are prepared to undertake dinners such as would be suitable for our members at the present time. One of the greatest difficulties is in connection with the attendance, and of course there is also the increasing difficulty in regard to food. At one time I was afraid the idea would have to be abandoned altogether, but it has been found that we could arrange for a dinner of the kind at the Waterloo Tavern in the Haymarket. A point in its favour as regards this Institution is that the cooking is done electrically. The matter has been discussed at the Council Meeting this afternoon, and the Council are wholly in favour of my suggestion; that is to say, they think that to arrange for a dinner of this kind would be very desirable in normal times. They also agree that the Council dinner should be merged in the general dinner of members ; but they do feel very grave doubt as to whether this is an opportune time to institute such an arrangement. In the first place there is the danger that even though started it might fall through very quickly on account of food restrictions and of the other serious difficulties of arranging for anything of the kind. It is also suggested that some members might not consider it to be quite the right thing to dine together at such a time as this. This is perhaps not a very strong objection, because the dinner would not be in any sense a jollification ; everybody must have something to eat after the meeting, and the main object would be to promote intercourse among the members. That, of course, is a matter in which the Council would naturally defer to the feeling of the members if it were generally felt that such a dinner ought not to be attempted at the present time. There are two

aspects of the question which occur to me, and they are opposed to each other. In the first place, by instituting this dinner on this extremely modest scale and in this very unpretentious manner, should we be promoting a function which would develop into something very much better later on? In other words, should we be leading up to what I feel most strongly to be very desirable? Or should we be running the risk of failure by not beginning on an ambitious enough scale? I confess that I myself am rather doubtful. I think on the whole the former is the more likely development, and that, beginning in this modest way, the thing would grow. The Council decided this afternoon to consult the general body of members on this matter, and that if the members desire such a function arrangements will be made for it. If, however, the members think the time is inopportune—and I am bound to say that on the whole the Council is of the opinion that it is not opportune—then we will not arrange for it. For my own part I confess that I should like to see it tried, but I appreciate very strongly the difficulties in the way, and I should certainly not try to force the scheme at all unless there were some general feeling in favour of it. It can hardly be discussed now, but no doubt the Press will take notice of this suggestion, and I would ask those who would like such a dinner to be arranged to send in their names to the Secretary. If a sufficient number do so, I think the Council will be inclined to take that as an indication that the general body of members approve of the suggestion, and the experiment will be tried.

Promotions, Transfers, etc., of Members on Military Service.

(Tenth List.*)

Members.

Name.	*Corps, etc.*	*Rank.*
Richardson, H., M.C.	City of Dundee (Fortress) R.E.	Major
Webber, O. T. O'K.	Royal Engineers	Major

Associate Members.

Booth, J. M. M.	Durham Light Infantry	2nd Lieut.
Childs, H. B. T.	Royal Flying Corps	Major
Coghlan, J., M.C.	Australian Field Engineers	Major
Cross, H.	Australian Imperial Force	Captain
Davies, L. H., M.C.	Royal Garrison Artillery	Actg. Capt.
Fraser, D. M.	Royal Engineers	Sergeant
Gillespie, W.	Royal Engineers	Major
Harris, R. A.	Hampshire (Fortress) R.E.	Lieutenant
Hartley, J. B.	Royal Garrison Artillery	Lieutenant
Hodson, W.	Tank Corps	2nd Lieut.
Horne, W. J. A. E.	Royal Garrison Artillery	Captain
Lee, H. B.	Royal Engineers, attd. R.F.C.	Lieutenant
Lisle, A.	Royal Engineers	Lieutenant
MacDougall, J. K.	Pioneer Reinforcements	Lieutenant
Mohr, S. M., M.C.	Sherwood Foresters	Major
Newman, A. R.	Royal Navy	Warrant Eng.
Nimmo, H. W.	London Electrical Engineers, R.E.	Lieutenant
Perry, C. S.	Royal Engineers	Captain
Philipp, R.C., M.C.	Royal Engineers	Lieutenant

* See *Journal I.E.E.*, vol. 51, pp. 307, 404, 579, and 675; vol. 55, pp. 59, 195, 327, and 539; and *Institution Notes*, No. 2, p. 8.

Associate Members.—*continued.*

Name.	*Corps, etc.*	*Rank.*
Phillips, N. D. B.	Royal Engineers	Lieutenant
Pocock, P. C.	Royal Engineers	Staff Sergt.
Reed, H. K.	Royal Engineers	Lieutenant
Rice, R. K.	R.N.V.R.	Lieutenant
Ross, J. D.	London Electrical Engineers, R.E.	Captain
Sargent, G. H.	Tank Corps	Captain
Troutet, F.	French Flying Corps	Sous-Officier
Webb, H. J. G.	Royal Engineers	Lieutenant
Wenger, T.L., M.C.	Tank Corps	Captain

Graduates.

Harriss, G. S.	Royal Engineers	Lieutenant
McLean, W.A.G.	Calcutta Scottish Volunteers	Sergeant
Newman, A. S.	Royal Engineers	Corporal
Sahgal, S. R.	Royal Engineers	Warrant Officer

Students.

Barton, G. E.	Royal Engineers	Lieutenant
Braathen, E.	Royal Flying Corps	Corporal
Brazel, C. H.	Royal Engineers	Major
Charley, R.M., M.C.	Royal Flying Corps	Captain
Clarke, C. V.	South Staffordshire Regt.	Lieutenant
Doyle, H.	Royal Engineers	Lance-Corpl.
Ferranti, V. Z. de	Royal Engineers	Captain
Gibbard, H. E.	Royal Engineers	Cadet
Glover, E. H.	Royal Engineers	Lieutenant
Gordon, E. A.	Royal Engineers	Sergeant
Harrison, R. W.	Royal Engineers	Sapper
Hawkins, C. E.	Royal Engineers	Cadet
Hayes, L. W.	Royal Engineers	2nd Lieut.
Jepson, C.	Royal Naval Air Service	Leading Mechanic
Jones, L. J.	Royal Flying Corps	1st-Class Air Mechanic
Kerr, W. W.	Royal Garrison Artillery	2nd Lieut.
Krasemann, H. A.	London Electrical Engineers, R.E.	Lance-Corpl.
Lane, C. F.	Royal Engineers	Corporal
Lawrence, F. C.	West Yorkshire Regt.	Lieutenant
Lee, H. J.	Royal Engineers	Corporal
Leeson, B. E.	Royal Flying Corps	2nd Lieut.
Linay, R. E. M.	Royal Flying Corps	2nd-Class Air Mechanic
Lloyd, W. F.	Royal Garrison Artillery	2nd Lieut.
Mabbs, E. G.	Royal Engineers	Sapper
Mackie, A. P.	New Zealand Engineers	Lance-Corpl.
McWhinnie, D. R.	Hampshire Regt., attd. R.F.C.	2nd Lieut.
Marks, E.	Yeomanry	Sergeant
Miller, J. A.	Royal Engineers	Lieutenant
Norburn, W. H. J.	Hampshire (Fortress) R.E.	Lieutenant
Ostler, P.	City of Edinburgh (Fortress) R.E.	2nd Lieut.
Peattie, J. D.	Royal Engineers	2nd Lieut.
Rogers, A. H. E.	Royal Engineers	2nd Lieut.
Ross-Bain, G.	Manchester Regt.	Captain
Seagrave, H. G.	York & Lancaster Regt.	2nd Lieut.
Slingerland, J. F.	London Electrical Engineers, R.E.	2nd Lieut.
Wadeson, M.	Tank Corps	Lieutenant
Welch, J. G. L.	Royal Garrison Artillery	Captain
Wormull, C. F.	Royal Flying Corps	Lieutenant
Young, H. V.	Royal Flying Corps	2nd Lieut.

Institution Staff.

Ashford, H. J.	Royal Fusiliers	Lance-Corpl.

Addresses Wanted.

The present addresses of the following members are required for the Institution Register :—

Name.	*Last Address.*
MEMBERS.	
H. C. Bishop	16, Quay Street, Cardiff.
R. P. Brousson	47, Parliament Street, Westminster, S.W.
W. Clark	61, Ermine Road, Lewisham, S.E.
C. H. Douglas	Engineer-in-Chief's Office, General Post Office, E.C.
W. E. D. Duncan	Messrs. Duncan Campbell & Co., 8, Waterloo Place, S.W.
C. W. Durnford	4, St. Stephen's Avenue, Ealing, W.
L. H. S. Ellson	345, St. George's Terrace, Perth, W. Australia.
J. Enright	202, Holland Road Kensington, W.
R. E. Fletcher	Grosvenor, Church Street, Devonport, Auckland, N.Z.
C. E. Hunter	Denholme, Windmill Hill, Enfield, N.
P. D. Ionides	124, St. Vincent Street, Glasgow.
A. Jourdan	Chez M. Paul Talon, Zone du Village, A Marseilles, France.
T. A. Locke	8, Thurloe Road, Worthy Lane, Winchester.
Captain G. T. W. Olver, R.E.	R.E. Mess, Aldershot.
C. A. L. Prüsmann	2, Queen's Road, Sketty, Swansea.
H. Snowdon	285, Lewisham High Road, St. John's, S.E.
ASSOCIATE MEMBERS.	
W. McL. Arnot	Siemens Bros. Dynamo Works, Ltd., 42, Bridge Street, Sydney, Australia.
F. C. D. Atkin	Usine Electrique, Municipalite De Beni-Souef, Egypt.
H. H. S. Baker	105, Ebury Street, Belgravia, S.W. 1.
H. Bond	11, Yateley Road, Edgbaston, Birmingham.
W. R. Brown	66, Lordship Lane, Dulwich, S.E.
C. A. Butlin	Lista De Correos, San Juan De Porto Rico, South America.
C. F. Button	28, Glebe Road, Peterborough.
W. J. I. Casewell	118, Haverstock Hill, N.W.
Lieut.-Col. S. H. Cowan, D.S.O., R.E.	46, Moscow Court, W.
F. B. Cramer	48, Maple Road, Surbiton.
Lieut. J. P. Crowther, A.O.D.	157, Church Lane Charlton, S.E. 7.
Sapper W. H. St. A. Davies, R.E.	Bere Island (East End), Bantry Bay.
Lieut.-Col. L. Evans, D.S.O., R.E.	c/o Messrs. Cox & Co., 16, Charing Cross, S.W. 1.
2nd Lieut. H. Green, R.E.	Signal Depot, Fenny Stratford, Bucks.
H. C. Heath	Cleveland Street, Burslem, Staffs.
D. Jackson	G.P.O. Testing Branch, Mount Pleasant, E.C.
G. Johnson	80, Pendarves Road, Tuckingmill, Cornwall.
Z. D. King	423, Chekiang Road Shanghai.

Name.	*Last Address.*
ASSOCIATE MEMBERS—*continued.*	
E. H. Leonardt	163, Howard Road, Walthamstow, N.E.
M. B. Logan	322, Donald Street, Winnipeg, Canada.
M. E. Macdonald	Rosherville Power Station, Cleveland, Transvaal.
A. W. Maley	Westbourne Road, New Inns, Handsworth, Birmingham.
N. M. Marshall	Canada Buildings, Bombay, India.
A. A. Maytham	Maytham Tin and Steelware, Ltd., East London, South Africa.
F. A. Menzies	Municipal Electrical Engineer, Mussoorie, U.P., India.
P. Miley	47, Vickers Road, Firth Park, Sheffield.
W. H. Moore	Superintendent Engineer to Port Commissioners, Calcutta.
J. Murray	Cheam Cottage, Summerley Road, Kenilworth, Cape Colony.
C. E. F. Parker	Elmside, Elmhurst Road, Gosport.
H. E. Parry	184, Cricklewood Broadway, N.W.
R. B. Perring	Dickapitiya, Haputale, Ceylon.
E. Probert	820, Central Building, Sixth and Main Streets, Los Angeles, Cal., U.S.A.
J. I. Robertson	5, Bruntsfield Gardens, Edinburgh.
R. J. Rosser	Corporation Electricity Works, Dock Road, Cape Town.
H. Rust	80, Monica Grove, Levenshulme, Manchester.
A. Sadler	c/o Messrs. Huttenbach & Co., Penang, Straits Settlements.
C. E. Savage	Earl of Dudley's Baggeridge Wood Colliery, Sedgley, Worcester.
E. Sayer	27D, London Road, Forest Hill, S.E.
R. Scruby	Sanctuary House, Westminster S.W.
C. H. Shanan	Maple Hayes, Mussoorie, U.P., India.
C. W. Shepherd	Royal Holloway College, Englefield Green S.O., Surrey.
H. Skelton	16, Dinton Road, Kingston-on-Thames.
Captain R. E. Stace, R.E.	c/o Messrs. Cox & Co., Hornby Road, Bombay.
M. W. Staight	Messrs. The George A. Fuller Co., Ltd., Montreal, Canada.
F. C. Stephens	Government Buildings, Pretoria, South Africa.
W. Turner	114, Cromwell Road, South Kensington, S.W.
A. B. Wearing	Canadian Union Electric Co., Ltd., 130, Wellington Street, West Toronto.
A. G. Whitfield	Public Works Dept., Taiping, Perak, F.M.S.
H. Whitworth	52, Westcliff Park Drive, Westcliff-on-Sea.
A. E. Wilkins	13, Belvedere Place, Dublin.
E. Rudland Wood	Clarence Chambers, Parliament Terrace, Harrogate.
G. H. Wyatt	13 & 14, Bussey Buildings, Loveday Street, Johannesburg, Transvaal.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 4. March 1918. INSTITUTION NOTES. [ISSUED WITH No. 272 OF THE JOURNAL.]

Forthcoming Meetings.

MEETINGS OF THE INSTITUTION.

Date. 1918.	*Author and Title of Paper*
7 Mar	E. B. Wedmore: "The Control of Large Amounts of Power."
21 Mar.	S. F. Barclay: "The Mechanical Design and Specification of the Turbo-Alternator Rotor."
11 Apr.	Joint Meeting with Electrical Section of the Royal Society of Medicine: Papers on "Medical Electricity." (Also exhibition of electro-medical apparatus.)
18 Apr.	L. Andrews: "Overseas Distribution of Engineering Appliances."
25 Apr.	E. C. McKinnon: "Large Batteries for Power Purposes."
9 May	Discussion on "A British Electrical Proving House" with an introductory paper by C. Turnbull.
23 May	Professor E. W Marchant: "Some Transient Phenomena in Electrical Supply Systems."
30 May	Annual General Meeting.

LOCAL SECTIONS.

Date. 1918.	*Place of Meeting.*	*Author and Title of Paper.*
11 Mar.	Bristol	Annual General Meeting. E. B. Wedmore: "The Control of Large Amounts of Power."
11 Mar.	Newcastle	C. C. Garrard: "Switchgear Standardization."
12 Mar.	Edinburgh	C. M. Jacobs: "Electrical Signalling and Control on Railways."
12 Mar.	Leeds	S. F. Barclay: "The Mechanical Design and Specification of the Turbo-Alternator Rotor."
12 Mar.	Manchester	E. B. Wedmore: "The Control of Large Amounts of Power."
20 Mar.	Birmingham	E. B. Wedmore: "The Control of Large Amounts of Power."
26 Mar.	Dublin	Discussion on Coal Conservation Sub-Committee's Report.
26 Mar.	Manchester	S. F. Barclay: "The Mechanical Design and Specification of the Turbo-Alternator Rotor."
8 Apr.	Newcastle	E. B. Wedmore: "The Control of Large Amounts of Power."
9 Apr.	Glasgow	Annual General Meeting. E. B. Wedmore: "The Control of Large Amounts of Power."
9 Apr.	Leeds	Annual General Meeting.
9 Apr.	Manchester	Captain W. P. Digby: "Contract Prices during Demobilization."
17 Apr.	Birmingham	Annual General Meeting. E. C. McKinnon: "Large Batteries for Power Purposes."

LOCAL SECTIONS—*continued.*

Date. 1918.	*Place of Meeting.*	*Author and Title of Paper.*
23 Apr.	Manchester	Annual General Meeting. Address by the President (Mr. C. H Wordingham).
13 May	Newcastle	Annual General Meeting.

STUDENTS' SECTION.

Date. 1918.	*Place of Meeting.*	*Author and Title of Paper.*
22 Mar.	City and Guilds (Engineering) College, South Kensington (7 p.m.)	Address by the President (Mr. C. H. Wordingham).

Ordinary Meeting of 11 April, 1918.

The Joint Meeting with the Royal Society of Medicine on the 11th April, 1918, will be held at King's College, Strand, W.C.

Extra Meeting, 18 April, 1918.

In addition to the arrangements set out on the Meetings Card for the Second Half of the Session, an Ordinary Meeting will be held on the 18th April, 1918, at the Institution of Civil Engineers, when a paper will be read by Mr. L. Andrews entitled "Overseas Distribution of Engineering Appliances."

Patents and Designs Bill.

A private and informal meeting of Members, Associate Members, and Associates was held on the 28th February, 1918, for the purpose of discussing the provisions of the above Bill.

Street Lighting Specifications.

The Standard Clauses for Street Lighting Specifications recommended in the Majority Report of the Street Lighting Specification Committee (see *Journal I.E.E.*, 1917, vol. 55, p. 522) have been published in pamphlet form. Copies can be obtained from the Secretary of the Institution, price threepence each, or fourpence post-free.

Rontgen Society.

Dr. W. H. Eccles and Mr. J. E. Taylor have been nominated to serve as the representatives of the Institution on an Advisory Committee which has been formed by the Röntgen Society to advise on points of interest connected with the British X-ray industry.

Fuel Oil Committee.

A Committee was appointed by the Council on the 13th December, 1917, to consider the question of the supply and prices of fuel oils to Electricity Supply Undertakings. After two meetings had been held, a deputation of the Committee waited upon the Controller of Munitions Mineral Oil Production. The result was highly satisfactory, and the Controller decided that a Committee of the Diesel Engine Users' Association should, in co-operation with him, arrange for the supply of suitable oils, etc., to Electricity Undertakings.

On the invitation of the Association, it was agreed that the Institution should nominate three representatives to serve on this Committee, and Messrs. A. H. Dykes, W. Fennell, and J. C. Wigham have been nominated by the Council for that purpose.

As a further result of the Deputation a circular letter was addressed by the Controller to users of Diesel engines, advising the adoption of tar oils under licence from the Department, and offering to assist in adapting Diesel engines for the consumption of tar oils, by obtaining priority for the necessary material and engine alterations.

Scottish Local Section.

The President (Mr. C. H. Wordingham), accompanied by the Secretary, attended a meeting of the Scottish Local Section on Tuesday, 12th February, 1918, when Professor Magnus Maclean gave the Kelvin Lecture, which he had delivered before the Institution the previous week.

The Chairman of the Local Section, Mr. A. Page, presided.

The President addressed the members, and in his remarks referred, among other matters, to the importance of developing the Local Sections, the rules for electrical installations on ships (at present being drafted by a Committee of the Institution), research, the Patent Law, and the proposed national electrical proving house for British manufactures.

The Institution.

At the meeting of the Scottish Local Section on the 12th February, 1918, Colonel Malcolm of Poltalloch made the following remarks :—

"The genesis of this Institution which now has a membership of over 7,000 was as follows. A brother officer of mine, the late Captain (afterwards Major-General) Charles Webber, was in charge of some telegraph sappers in London and made the acquaintance of Sir William Siemens, then a manufacturer of electrical instruments, etc., and they discussed the question of gathering the members of the body of telegraph engineers into an Institution like this. And Webber said to me : 'Will you join ?' and I said I would. 'That makes three,' said Webber, 'now we can start.' We started, and in a short time a lot of others joined, and from that modest beginning we have such a meeting as this, not only here but all over the world. I had not very much to do with it, as I was at Chatham where I had to turn soldiers into military telegraphers and work out the defence of the country by submarine mines. When this work was thoroughly understood by the soldiers, it was suddenly put an end to by the efforts of the Navy. I believe that if we had been allowed to continue, the results would have been very useful at a time like the present. The submarine work was stopped, but I think people have come to see that there was something in it. There is only one other matter I wish to mention to-night. In those days I did one thing for members which met with a great deal of opposition from one section of the Society. There was a great desire to increase the funds, and it was proposed to turn this necessity into an opportunity for admitting female telegraph operators as members. Then it would have become a mere dot-and-dash Society. I strenuously opposed the proposal and saved the Society, which is now one of the most important technical Institutions in the world."

The Late Sir John Wolfe Barry.

At the Ordinary Meeting of the Institution on the 24th January, 1918, the President, in referring to the death of Sir John Wolfe Barry, K.C.B., F.R.S., said :

"Within the last two or three days a great engineer has passed away—one whose voice has often been heard within these walls (The Institution of Civil Engineers). Sir John Wolfe Barry was one of the pillars of the engineering profession, and one of those who had done most to make that profession attain the honoured position which it now holds. We have the honour of reckoning him among the members of our own Institution. As is well known probably to most of those present, it was Sir John Wolfe Barry who originated the idea of the Engineering Standards Committee, a body to which our Institution owes so much even now, and will in the future owe a very

great deal more. It is only a few weeks ago that in this room Sir John Wolfe Barry gave an account of the work of that Committee. At that time he was in good health. It must have been to many of his friends a very great shock, as it was to me, to see his death recorded in the papers. There is a satisfaction, however, in knowing that to the last he had every faculty intact and was taking the fullest possible interest in the daily affairs of the profession and of the nation. It is, I think, a fate that all of us who may be destined to arrive at a great age must covet—to die in harness and in full possession of our faculties, as he was. I am sure that I shall be consulting the wishes of the members if I ask those present to stand and record a vote of sincere condolence with Sir John Wolfe Barry's family."

British Engineering Standards Committee.

A Panel of the Sub-Committee on Nomenclature has been formed to draft a list of terms and definitions used in connection with automatic telephones. The constitution of this Panel is as follows :—

Mr. A. P. Trotter (*Chairman*)	
Mr. A. J. Stubbs ..	Post Office.
Mr. B. O. Anson ..	
Mr. W. H. Grinsted	Automatic Telephone Manufacturing Association.
Mr. E. A. Laidlaw ..	
Mr. J. W. Catchpole	Automatic Telephone Manufacturing Company, Ltd.

A preliminary list of terms and definitions has been drafted and every effort will be made to obtain Anglo-American agreement in this matter.

Any members of the Institution interested in this subject should communicate with the Secretary, British Engineering Standards Committee, 28 Victoria Street, S.W. 1.

British Standard Specifications for Electrical Apparatus.

A list of the above is enclosed with this issue of the *Journal*.

Roll of Honour.

(Ninth List.*)

Killed in Action.		
Barnett, 2nd Lieut. E. J.	Royal Engineers	Student
Butler, Lieut. A. E. W.	Royal Berkshire Regt.	Student
Cunningham, 2nd Lieut. P. N.	Highland Light Infantry	Student
Goodwin, Gunner J. J.	Machine Gun Corps	Student
Wormull, Lieut. C. F.	Royal Flying Corps	Student
Died of Wounds.		
Cardew, Lieut. J. H., M.C.	Royal Field Artillery	Associate Member
Hickie, Lieut. C. S.	Royal Flying Corps	Associate Member
Young, 2nd Lieut. H. V.	Royal Flying Corps	Student
Accidentally Killed.		
Barlow, Flight-Com. L. M., M.C.	Royal Flying Corps	Student
Warden, E. A.	Canadian Field Artillery	Student

* See vol. 54, pp. 64, 447, and 675; vol. 55, pp. 55, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3.

Military Honours Awarded.

(Ninth List.*)

C.M.G.		
Bagnold, Colonel A. H., C.B.	Royal Engineers	Member
Davy, Lieut.-Col. C. W.	Royal Engineers	Member
Drummond, Brig.-Gen. H.H.J.W.	T.F. Reserve	Associate
Distinguished Service Order.		
Glendenning, Major S. E.	Royal Engineers	Member
Minshall, Col. T. H.	General List	Member
Hardie, Major C. C. A.	Royal Engineers	Associate Member
Layton, Lieut.-Col. A. B.	Lancashire Regt.	Associate Member
O'Brien Colonel H. E.	Royal Engineers	Associate Member
Military Cross.		
Richardson, Major H.	Royal Engineers	Member
Angwin, Major A. S.	Royal Engineers	Associate Member
Charley, Captain R. M.	Royal Flying Corps	Student
Coghlan, Major J.	Australian Field Engineers	Associate Member
Davies, Actg.-Capt. L. H.	Royal Garrison Artillery	Associate Member
Hurlbatt, Captain E. S.	Manchester Regt.	Associate Member
Kirkby, Captain H. McK.	Army Ordnance Dept.	Associate Member
Lincoln, Major J. W.	Royal Engineers	Associate Member
Lovell, Lieut. W. H.	Grenadier Guards	Associate Member
Marston, Major G. S.	Royal Engineers	Associate Member
Maxwell, Captain K. G.	Manchester Regt.	Associate Member
Milnes, Captain G. C.	Royal Lancaster Regt.	Associate Member

"For conspicuous gallantry and devotion to duty during a period of several days under heavy shell fire. After standing in water for over twenty-four hours, some of his men showed signs of wavering, whereupon he ran along the entire line battalion front, rallied the men, reorganized the line, and did a great deal by his personal example to save what would have become a bad situation." —*London Gazette*, 9 January, 1918.

* See vol. 54, pp. 306, 518, and 674; vol. 55, pp. 56, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3.

Military Cross.—*continued.*

Philipp, Lieut. R. C.	Royal Engineers	Associate Member
Sizer, Lieut. N.	Royal Engineers	Associate Member
Tyler, Major H. W.	Royal Engineers	Associate Member
Wenger, Captain T. L.	Tank Corps	Associate Member
Hunter, Captain W. H.	Army Service Corps	Associate
Jones, Captain E. F.	Royal Field Artillery	Graduate
Otter, Captain F. L.	London Regt.	Graduate
Ballard, 2nd Lieut. F. L.	Royal Field Artillery	Student
Dawnay, Captain C.	Yorkshire Regt.	Student
Grose, Actg.-Capt. S. J.	Royal Field Artillery	Student
Protheroe, Captain R. N.	Royal Field Artillery	Student
Riley, Lieut. H.	Royal Engineers	Student
Smith, Captain L. C. R.	*Royal West Kent Regt.	Student
Stone, Lieut. H. J.	Royal Engineers	Student
Taylor, Captain K. B.	Royal Welsh Fusiliers	Student

Legion of Honour (Croix de Chevalier).

Mallison, Captain G. G.	Royal Garrison Artillery	Associate Member
Speir, Major K. R. N.	Royal Engineers	Associate Member

Mentioned in Despatches.

Dillon, Lieut. T. F.	Royal Engineers	Associate Member
Ewer, Lieut.-Col. G. G., D.S.O.	Essex Regt.	Associate Member
Kirkby, Captain H. McK., M.C.	Army Ordnance Dept.	Associate Member
McMahon, 2nd Lieut. V. H. M.	Army Service Corps	Associate Member
O'Brien, Colonel H. E., D.S.O.	Royal Engineers	Associate Member
Seeley, Lieut. C. G.	Royal Engineers	Associate Member
Sizer, Lieut. N., M.C.	Royal Engineers	Associate Member
Tyler, Major H. W., M.C.	Royal Engineers	Associate Member
Ditmas, Captain F. I. L., M.C.	Durham Light Infantry	Associate
Taylor, Captain K. B.	Royal Welsh Fusiliers	Student

Members on Military Service.

(Fourteenth List.*)

Members.

Name.	*Corps, etc.*	*Rank.*
Hancock, W. J.	Australian Army Medical Corps	Lieutenant
Murphy, L.	R.N.V.R.	Lieutenant

* See vol. 53, pp. 199, 320, 388, and 857; vol. 54, pp. 121, 403, 518, and 675; vol. 55, pp. 57, 104, 326, and 538; and *Institution Notes*, No. 1, p. 4.

Associate Members.

Name.	*Corps, etc.*	*Rank.*
Bentley, C. W.	Royal Flying Corps	2nd Lieut.
Bertin, P. H.	Royal Flying Corps	Lieutenant
Brown, C. L.	Royal Engineers	Lieutenant
Brown, R. A.	R.N.V.R.	Sub-Lieut.
Browne, W. L.	Army Service Corps	Corporal
Burns, S.	Army Ordnance Dept.	Lieutenant
Colley, L. J. St. John	Royal Engineers	Major
Davis, A. L.	R.N.V.R.	Lieutenant
Ellis, R. G.	Tyne Electrical Engineers, R.E.	Lieutenant
Follenfant, C.	Royal Engineers	2nd Lieut.
Gomersall, L. A.	Honourable Artillery Company	Driver
Lee, A. G., M.C.	Royal Engineers	Major
McCormick, B.	R.N.V.R., attd. R.N.A.S.	Lieutenant
Mellor, F.	Royal Engineers	Lance-Corpl.
Miller, J. F. X.	Army Ordnance Dept.	Lieutenant
Polden, C. J.	Royal Flying Corps	2nd Lieut.
Rennie, J. C.	R.N.V.R.	Lieutenant
Robinson, H. J.	Royal Flying Corps	Lieutenant
Rudd, S.	Royal Garrison Artillery	2nd Lieut.
Ruderman, L. L.	Royal Engineers	Staff-Sergt.
Sibree, J. O.	Royal Engineers	Lieutenant
Souden, F. H.	Royal Engineers	Sapper
Thompson, W. B.	Army Ordnance Dept.	Lieutenant
Turner, S.	Royal Flying Corps	Lieutenant
Winkworth, L. S.	Royal Engineers	2nd Lieut.

Graduates.

Annear, J. C.	Royal Engineers	Captain
Bingham, J. H.	General Staff	Lieutenant
Blackburn, H. A.	Royal Naval Air Service	Warrant Officer
Elphick, E. de B.	London Electrical Engineers, R.E.	Corporal
Garrett, H. R.	Royal Engineers	Lieutenant
Meade, J. H.	Royal Flying Corps	Lieutenant
Muir, C. W.	Royal Navy	Lieutenant
Sleigh, C. C.	Royal Naval Air Service	Prob. Flight Officer
Wybrow, S. G.	Royal Naval Air Service	Warrant Officer

Students.

Bennett, O.H.D.	Royal Naval Air Service	Prob. Flight Officer
Bulley, H. N.	Royal Navy	Wireless Officer
Church, L. P.	Royal Engineers	Pioneer
Clark, R. C. L.	London Electrical Engineers, R.E.	Sapper
Corner, H.	Durham University, O.T.C.	Cadet
Fitzgerald, A. S.	Royal Flying Corps	2nd-Class Air Mechanic
Garwood, G. T.	Royal Naval Air Service	Air Mechanic
Harben, J. E.	Royal Engineers	Lieutenant
Hayne, E. T., D.S.C.	Royal Naval Air Service	Flight Lieut.
Howard, A.	London Electrical Engineers, R.E.	Sapper
Lane, G. N. S.	Royal Naval Air Service	Prob. Flight Officer
Parr-Dudley, E.A.	London Electrical Engineers, R.E.	Corporal
Schamasch, A.	Royal Engineers	Sapper
Serner, A.	Royal Field Artillery	Driver

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 5. April 1918. INSTITUTION NOTES. [ISSUED WITH No. 273 OF THE JOURNAL.]

Forthcoming Meetings.

MEETINGS OF THE INSTITUTION.

Date.	*Author and Title of Paper.*
1918.	
11 Apr.	Joint Meeting (at the Cancer Hospital, Fulham Road, S.W.) with the Electrical Section of the Royal Society of Medicine, and exhibition of electro-medical apparatus.
	Dr. E. P. CUMBERBATCH: "Diathermy: The Use of the Electrical Current to raise the Temperature of the Body in the Treatment of Disease."
	Dr. R. KNOX: "Single Impulse Radiography (Instantaneous): Its Limitations and Possibilities.
18 Apr.	L. ANDREWS: "Overseas Distribution of Engineering Appliances."
25 Apr.	E. C. MCKINNON: "Large Batteries for Power Purposes."
9 May	Discussion on "A British Electrical Proving House," with an introductory paper by C. TURNBULL.
23 May	Professor E. W. MARCHANT: "Some Transient Phenomena in Electrical Supply Systems."
30 May	Annual General Meeting.

LOCAL SECTIONS.

Date.	*Place of Meeting.*	*Author and Title of Paper.*
1918.		
8 Apr.	Newcastle	E. B. WEDMORE: "The Control of Large Amounts of Power."
9 Apr.	Glasgow	Annual General Meeting.
		E. B. WEDMORE: "The Control of Large Amounts of Power."
9 Apr.	Leeds	Annual General Meeting.
		Visit by the President (Mr. C. H. Wordingham).
		J. H. SHAW: "The Use of High-pressure and High-temperature Steam in Large Power Stations."
9 Apr.	Manchester	Captain W. P. DIGBY: "Contract Prices during Demobilization."
15 Apr.	Newcastle	Discussion on Coal Conservation Sub-Committee's Report.
17 Apr.	Birmingham	E. C. MCKINNON: "Large Batteries for Power Purposes."
23 Apr.	Manchester	Annual General Meeting.
		Address by the PRESIDENT (Mr. C. H. Wordingham).
6 May	Newcastle	Discussion on "Draft Regulations for the Electrical Equipment of Ships."
13 May	Newcastle	Annual General Meeting.
		Discussion on "A British Electrical Proving House," with an introductory paper by Mr. C. TURNBULL.

STUDENTS' SECTION.

Date.	*Place of Meeting.*	*Author and Title of Paper.*
1918.		
26 Apr.	University College, Gower Street (7 p.m.)	J. A. BROUGHALL: "Electric Steel Furnaces."
15 May	Finsbury Technical College (7 p.m.)	Annual General Meeting.

Council Nominations for Election to the Council.

The following have been nominated by the Council for the vacancies which will occur in the offices of President, Vice-Presidents, Honorary Treasurer, and Ordinary Members of Council on the 30th September, 1918:—

President. (*One Vacancy.*)

C. H. WORDINGHAM.

Vice-Presidents. (*Two Vacancies.*)

W. A. Chamen. R. A. Chattock.

Honorary Treasurer. (*One Vacancy.*)

J. E. Kingsbury.

Ordinary Members of Council.

MEMBERS. (*Five Vacancies.*)

F. Ayton. Prof. E. W. Marchant D.Sc.
H. W. Clothier. C. C. Paterson, O.B.E.
A. C. Cramb. J. Sayers.
A. R. Everest. Prof. E. Wilson.
Sir R. A. Hadfield, Bart., F.R.S.

ASSOCIATE. (*One Vacancy.*)

D. N. Dunlop.

Technical Work in Connection with the War.

Members of the Institution who have been invalided out of H.M. Forces and are able to undertake technical work in connection with the War, are requested to send their names to the Secretary with full particulars of their qualifications.

I.E.E. Wiring Rules.

The Council have adopted a recommendation of the Wiring Rules Committee that Wiring Rule No. 62 shall not apply to consumers' electric supply meters for currents up to 100 amperes made in accordance with the Engineering Standards Committee's Specification No. 37.

Portrait of Galileo.

At the Ordinary Meeting of the Institution on the 21st March, 1918, Mr. C. P. Sparks, Past President, presented to the Institution an oil painting of Galileo. This is a copy by William Bradley, about 1825, of a painting by Susterman in 1635, now in the Uffizi Gallery, Florence.

Mr. L. B. Atkinson has generously offered to defray the cost of printing a sufficient number of copies of the portrait for distribution among the members. These copies will be inserted in a future number of the *Journal* in the form of a loose inset.

A paper by Mr. J. J. Fahie describing Galileo's work in connection with lodestones will be found on page 246 of the present number of the *Journal*.

British Engineering Standards Committee.

The Secretary of the Standards Committee regrets that there was an error in the notice regarding the above which he supplied for publication in the last number of *Institution Notes* (No. 4, March 1918, page 15).

The words "Automatic Telephone Manufacturing Association" should be "Telephone Manufacturers' Association." The representatives of the Association on the Panel are now Mr. E. A. Laidlaw and Mr. F. K. Jewson.

Members on Military Service.

(Fifteenth List.*)

Member.

Name.	*Corps, etc.*	*Rank.*
Slacke, R. B.	Royal Engineers	Captain

Associate Members.

Belfield, S. St. G. C.	Royal Naval Air Service	Flight Com.
Burns, J.	Royal Engineers	Lieutenant
Crawford, J. D.	Australian Engineers	Lieutenant
Eastwood, A.	Royal Flying Corps	Corporal
Hunter, R.	Royal Engineers	Lieutenant
Hyde-Thomson, D. H.	Royal Air Force	Lieut.-Col.
Levett, J. V.	Aeronautical Inspection Directorate	Deputy Asst. Inspector
Long, S. H.	Royal Engineers	Major
Malpass, J. B.	Royal Engineers	Captain
Marshall, C. R.	Royal Engineers	Lieutenant
Norie, J. R. D.	4th Canadian General Hospital	Chief Engr.
Phillips, R. W. L.	Royal Flying Corps	Lieutenant
Shepheard, H. B.	Royal Flying Corps	2nd Lieut.
Sloan, N. E. W.	Royal Irish Fusiliers	Lieutenant
Smith, T.	Royal Navy	Elec. Artificer
Thompson, E.G.G.	Australian Engineers	Sergeant
Wallroth, R. C.	R.N.V.R.	Lieutenant

Graduate.

Rose, P. T.	Royal Engineers	Actg. Capt.

Students.

Ambler, C.	Machine Gun Corps	Sergeant
Cook, P. H.	Royal Naval Air Service	2nd-Class Air Mechanic
Cope, E. L. N.	Royal Horse Artillery	Gunner
Greenwood, H. J.	Machine Gun Corps	Sergeant
Mann, H. C.	Royal Naval Air Service	Prob. Observer Officer
Scarf, C. T.	Royal Naval Air Service	1st-Class Air Mechanic
Sich, W. E. E.	Tyne Electrical Engineers, R.E.	Sapper
Simpson, E. W.	Royal Flying Corps	2nd Lieut.
Smith, R. H.	London Electrical Engineers, R.E.	Lance-Corpl.
Snipe, N. V.	Royal Naval Air Service	2nd-Class Air Mechanic
Taylor, A. T.	Royal Engineers	Lieutenant
Terry, T. W.	Royal Engineers	Sergeant
Wales, W. A.	Royal Flying Corps	2nd-Class Air Mechanic
Wall, H. H.	Royal Navy	Flight Sub-Lieut.
Watling, W. H.	London Electrical Engineers, R.E.	Sapper
Watts, A. J. C.	Royal Engineers	Pioneer
Whistler, H. A.	Dorsetshire Regt., attd. R.F.C.	Captain
Whittick, R. B.	Royal Flying Corps	Lieutenant
Wright, J. E.	R.N.V.R.	Lieutenant

* See *Journal I.E.E.*, vol. 53, pp. 199, 326, 388, and 857; vol. 54, pp. 121, 403, 518, and 675; vol. 55, pp. 57, 194, 326, and 538; and *Institution Notes*, No. 1, p. 4; No. 4, p. 16.

Promotions, Transfers, etc., of Members on Military Service.

(Eleventh List.*)

Members.

Name.	*Corps, etc.*	*Rank.*
Bishop, H. C.	Army Service Corps	Lieutenant
Holden, Sir H. C. L., R.A., K.C.B., F.R.S.	Staff-Director Mechanical Transport	Brig.-General
Kelly, A. C.	Royal Engineers	Major
O'Gorman, M. J. P., C.B.	T.F. Reserve	Colonel
Sparks, H. C., D.S.O., M.C.	Assistant Director of Labour	Colonel

Associate Members.

Baldwin, L. C.	Royal Engineers	2nd Lieut.
Battye, B. C., D.S.O.	Royal Engineers	Lieut.-Col.
Bazalgette, H. L.	London Electrical Engineers R.E.	Captain
Clark, A.	Royal Flying Corps	Lieutenant
Gill, D.	Royal Naval Air Service	Flight-Com.
Henderson, H. W. W.	Royal Engineers	Captain
Hurlbatt, E. S., M.C.	Manchester Regt.	Captain
Kidd, G. W.	Royal Navy	Eng. Lieut.-Com.
Laurie, D. S.	Royal Engineers	Captain
Lever, G. G.	Royal Flying Corps	Captain
Maxwell, K. G., M.C.	Manchester Regt.	Lieut.-Col.
Munday, G. W.	Royal Engineers	Lieutenant
Spence, J.	Royal Engineers	Lieutenant
Wells, J. K.	R.N.V.R.	Lieut.-Com.
Young, J.	Indian Army Reserve of Officers	Captain

Associate.

Hunter, W. H., M.C.	Army Service Corps	Captain

Graduates.

Jones, E. F., M.C.	Royal Field Artillery	Captain
Kirkpatrick, K. J.	Royal Garrison Artillery	2nd Lieut.
Manlove, C. W. W.	Royal Engineers	Lieutenant
Patel, N. B. B.	Bombay Rifles	Sergeant
Wouldham, A. W. P.	Machine Gun Corps	Lieutenant

Students.

Bailey, A.	Royal Engineers	Lieutenant
Ballard, C. M.	Royal Engineers	Lieutenant
Bulley, H. N.	Royal Air Force	2nd Lieut.
Cooke, H. R.	Royal Flying Corps	2nd Lieut.
Mittell, B. E. G.	Royal Engineers	Lieutenant
Morton, C. A.	Royal Flying Corps	1st-Class Air Mechanic
Ryle, P. J.	Royal Garrison Artillery	2nd Lieut.
Seagrave, H. G.	York & Lancaster Regt.	Lieutenant
Stone, H. J., M.C.	Royal Engineers	Lieutenant
Wadeson, M.	Tank Corps	Captain
Wheatley, E. K.	Royal Engineers	Sapper

Institution Staff.

Rayner, A. E.	Army Service Corps	Lance-Corpl.

* See *Journal I.E.E.*, vol. 54, pp. 307, 404, 579, and 675; vol. 55, pp. 59, 55, 327, and 539; and *Institution Notes*, No. 2, p. 8, and No. 3, p. 11.

Addresses Wanted.

The present addresses of the following members are required for the Institution Register :—

Members.

Name.	*Last Address.*
A. Eggington	Eastern Telegraph Co., 28, Via Venti Settembre, Rome, Italy.
E. S. Saunders	Room 28, Victory House, Cockspur Street, S.W.

Associate Members.

2nd Lieut. J. Ferguson, R.F.C.	Granville House, St. Albans Avenue, Weybridge.
W. C. S. Phillips	Central School of Science and Technology, Stoke-on-Trent.

Associates.

W. Challoner	Blackpool.
W. H. Derrimah	Halton House, 20–23, Holborn, W.C.
V. H. Gregory	Lynwood, Hornsey Lane Gardens, Highgate, N.
C. Isaac	New Phonopore Telephone Co., 31, Budge Row, E.C.
A. M. Keays	Corisande, Park Road, Bournemouth.
P. Mallick	Indian Government, Telegraph Dept., Sukkur, India.
G. Phillips	15, Rawlinson Road, Oxford.
F. W. Rayner	11, Thomson Road, Wealdstone, Middlesex.
C. A. Stephenson	3, Mostyn Road, Merton, Surrey.
F. C. Twemlow	132, Bury New Road, Higher Broughton, Manchester.

Graduates.

D. D. Barber	c/o T. Downey Esq., Multan Road, Lahore, India.
F. S. Beamish	32, Frederick Road, Aston, Birmingham.
H. G. Bennett	206, Springvale Road, Sheffield.
E. C. Channell	Power House, Jhelum Power Installation, Mahora, Rampur P.O., Kashmir.
A. G. Cross	70, Brunel Terrace, Westmoreland Road, Newcastle-on-Tyne.
E. C. Ives	Trent, Ferozepore Road, Lahore, India.
L. J. Jowit	113, Jackson Street, Stretford, Manchester.
A. L. Lintott	Beechlands, Chipstead, Surrey.
A. W. Marr	Kustore P.O., Maubhum District, Bengal, India.
H. A. Morris	Box 18, Koffyfontein, South Africa.
L. S. Richardson	15, Birch Grove, Liscard, Cheshire.
W. A. Welden	71, Marlow Road, Anerley, S.E. 20.

Students.

A. Mdunate	Faraday House, Southampton Row, W.C.
B. S. Benning	Marconi Engineer, c/o Edwardes Bank, Valparaiso, Chili.
P. S. Brett	16, Darley Street, Gorse Hill, Manchester.
T. S. Brunton	Westinghouse Erecting Engineer, c/o Tata Hydro-Electric Supply Co., Ltd., Bombay, India.

STUDENTS—*continued.*

Name.	*Last Address.*
Lieut. C. R. G. Cosens, R.E.	Signal Depot, R.E., Fenny Stratford, Bucks.
E. W. Cosserat	Albany House, Grosvenor Road, Rugby.
Lieut. F. C. Dixon	Oxford & Bucks L.I., British Expeditionary Force, France.
L. E. Felix-Smith	Arc Works, Chelmsford.
J. Galveas	Cascaes, Portugal.
T. C. C. Hawthorn	21, Allenby Street, Scunthorpe, Lincs.
H. V. Higby	99, Oakfield Road, Selly Park, Birmingham.
C. W. Jardine	c/o Standard Bank of S. Africa, Clement's Lane, E.C.

STUDENTS—*continued.*

Name.	*Last Address.*
H. J. Lee	Malvern Villas, Waverley Street, Worcester.
2nd Lieut. R.M.McNaught, R.E.	R.A. & R.E. Convalescent Depot Ripon.
J. H. Meacock	20, Mulgrave Road, Dollis Hill, N.W.
H. Pollard	8, Halifax Road, Littleborough, Lancs.
J. T. Rodwell	Canwick Vicarage, Canwick, Lincs.
D. E. K. Sanderson	64, Anson Road, Tufnell Park, N.
V. H. Wells	2nd-Class Air Mechanic, R.F.C., Cramlington, nr. Newcastle-on-Tyne.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 6. MAY 1918. INSTITUTION NOTES. [ISSUED WITH No. 274 OF THE JOURNAL.]

Forthcoming Meetings.

MEETINGS OF THE INSTITUTION.

Date.	*Author and Title of Paper.*
1918.	
9 May	Discussion on "A British Electrical Proving House," with an introductory paper by C. TURNBULL.
23 May	Professor E. W. MARCHANT: "Some Transient Phenomena in Electrical Supply Systems."
30 May	Annual General Meeting.

LOCAL SECTIONS.

Date.	*Place of Meeting.*	*Author and Title of Paper.*
1918.		
6 May	Newcastle	Discussion on "Draft Regulations for the Electrical Equipment of Ships."
7 May	Glasgow	Discussion on "Draft Regulations for the Electrical Equipment of Ships."
13 May	Newcastle	Annual General Meeting. Discussion on "A British Electrical Proving House," with an introductory paper by C. TURNBULL.
14 May	Leeds	Adjourned discussion on Mr. J. H. Shaw's paper ('The Use of High-pressure and High-temperature Steam in Large Power Stations").

STUDENTS' SECTION.

1918.		
15 May	Finsbury Technical College (7 p.m.)	Annual General Meeting.

Annual General Meeting, 30th May, 1918.

The Annual General Meeting of The Institution (Members, Associate Members, and Associates only) will be held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday, 30th May, 1918, at 6 p.m., to receive and consider the Annual Report of the Council and the Accounts for the year ended 31st December, 1917, and to elect Auditors.

The Report and Accounts will be found in the present number of the *Journal* (No. 274, pp. 330 and 338).

Nominations for Election to the Council.

In addition to those members nominated by the Council (see *Institution Notes*, No. 5, p. 17) the following members have been nominated for the undermentioned vacancies which will occur in the Council on the 30th September, 1918:—

As Vice-President.

S. L. Pearce *

As Ordinary Members of Council.

T. Roles.† E. B. Wedmore ‡

* Nominated by Messrs. C. J. Beaver, W. Cramp, J. Frith, E. M. Hollingsworth, F. M. Long, J. S. Peck, J. A. Robertson, E. Thomas, S. J. Watson, P. P. Wheelwright.

† Nominated by Messrs. R. H. Campion, W. Emmott, W. Hartnell, H. A. Nevill, P. J. Pybus, C.B.E., W. M. Rogerson, B. P. Scattergood, W. M. Selvey, E. C. Wallis, H. H. Wright.

‡ Nominated by Messrs. L. S. Carr, F. W. Carter, F. H. Clough, J. F. Crowley, V. O. Davis, W. Dixon, John Gray, P. Hamilton, C. W. G. Little, A. W. Jones, C. H. McCarthy-Jones, F. A. Nield, F. Samuelson, T. Stevens, G. Stevenson, A. M. Taylor, A. H. Walton, J. Harcourt Williams.

Employment of Engineers on Government Work.

The President has received from the Institution of Civil Engineers a copy of the following letter written on behalf of the Prime Minister in response to a letter signed by the Presidents of the Institutions of Civil, Electrical, and Mechanical Engineers:—

Copy.

10, DOWNING STREET,
WHITEHALL, S.W. 1.
10th April, 1918.

DEAR SIR,—I am desired by the Prime Minister to refer to your letter of the 19th March, and to thank you for the suggestion contained therein. Mr. Lloyd George accepts the principle of your recommendation that in connection with any engineering undertaking of a national kind the opinion of experienced Civil Engineers upon technical considerations should be sought in the initial stages and he has circulated the Institution's letter to the executive Departments concerned.

Yours faithfully,
(Signed) J. T. DAVIES.

H. E. JONES, Esq.

Galileo and Magnetism.

In connection with the paper on "Galileo and Magnetism" in No. 273 (April, 1918) of the *Journal*, the Secretary has received the following letter from Mr. Fahie :—

27 April, 1918.

DEAR SIR,

Referring to my paper on "Galileo and Magnetism" in No. 273 of the *Journal*, may I add a few words by way of completeness ?

On page 248 (1st column, line 35) after the word "power" the following words should be inserted :—"Thus, there is preserved in the University of Padua (cabinet of Physical Science) a stone armed by him. It weighs 2½ oz. and supports 100 oz." Also the words "Of such a one" in the same line should read "Of another small stone."

A photograph of the Padua stone can be seen on application at the Science Museum (Western Galleries), South Kensington.

Yours faithfully,
(Signed) J. J. FAHIE.

I.E.E. Wiring Rules.

The Council have adopted a recommendation of the Wiring Rules Committee that Rules Nos. 68 and 69 in the 7th edition of the Wiring Rules (issued March, 1916) be cancelled and that the following be substituted :—

New Rule 68*x*.—Unarmoured conductors having a sheathing containing not less than 95 per cent pure lead (the remainder consisting of rarer metals) and of a thickness not less than that specified in the Engineering Standards Committee's Report (No. 7) on "British Standard Copper Conductors" may be used provided that—

(*a*) They are supported by means of clips, saddles, or clamps of such form as will not indent or damage the sheathing and, if metallic, of some metal other than copper. The supports shall be at intervals sufficiently short to prevent appreciable sagging of the conductor.

Conductors when vertical shall be fixed by the same means, with supports at the same intervals, as when horizontal, unless they be inaccessible, when a length not exceeding 10 feet may be allowed between the supports provided that the upper support firmly grips the cable or wire and that where there is a change of direction from horizontal to vertical they are brought over a rounded support of a radius not less than 3 times the external diameter of the sheathing.

(*b*) They are protected by wood or metal casing or conduit where exposed to mechanical injury, and by metal conduit (Rule 63*a*) where buried in plaster, cement, or brickwork. Such conductors laid between floors and ceilings, between lath and plaster or other hollow partitions, or through partitions and walls, need not be so protected.

(*c*) They do not come into contact with damp brickwork or plaster.

(*d*) The metal sheathing of the conductors is earthed and is made electrically continuous throughout by means of wiped joints, or alternatively, by bonding clamps specially designed for the purpose or forming part of boxes or similar fittings entered by the conductors. The continuity of the sheathing shall comply with Rule 69*t* and the earthing with Rules 34 and 35.

New Rule 69*x*.—The resistance of the metal sheathing between any two points of a completed installation shall not exceed 2 ohms.

Manchester Local Section.

The President (Mr. C. H. Wordingham) visited the Manchester Local Section on Tuesday, 23rd April, 1918. He was received by Mr. C. J. Beaver, Chairman of the Local Section, and the members of the Committee, and attended the Annual General Meeting of the Section. After the conclusion of the business of the Annual Meeting, the President addressed the members present, and in the course of his remarks said, *inter alia* :

I have been nominated by the Council as President for a second year. I should like to explain why I took on the very grave responsibility of accepting that nomination. There are two aspects from which the office of President can be regarded. It may be looked upon as a kind of prize open to every member of the Institution, a prize to be awarded to those whom the Institution, for some reason or another, sees fit to honour. If that be the way in which the Presidency is to be regarded then I think clearly no individual is justified in accepting office a second year. The other aspect is that it is the highest possible opportunity of serving the Institution, and that is the point of view from which I have looked at the matter. In my Inaugural Address (*Journal I.E.E.*, 1918, vol. 56, p. 1) I ventured to sketch out a number of directions in which I thought the Institution might, with advantage, be developed, and so far as has lain in me I have done my utmost to follow out the programme I laid down ; but a year—or more especially a session—is an extremely short period in which to accomplish anything. A good deal of the work of the session, in the way of papers and so on, is settled in the preceding session, and it is impossible to carry through in one session any large measure of what one hopes is improvement or reform. I felt when the Council did me the honour to invite me to accept renomination, that much of the work I had begun—of course in saying that I fully recognize that the work is really done by the Council, but one has endeavoured to lend one's hand to the development—would to a large extent be wasted if it were dropped at this point. It was because I hoped, by taking office for a second session, I could see some of this work brought to fruition that I accepted the renomination. But I want to make it quite clear that

I do not think a President is justified in taking office a second year on personal grounds.

It is of the utmost importance to the Institut on that it should extend its influence in every possible way, and the way in which that influence can best be extended is, first of all, by cultivating and developing what we at present call the Local Sections, and by securing in some way or another the interest of every individual member in the work of those Local Sections and of the Institution as a whole. What appeals to me most strongly is that there are not really any Sections or Local Sections of the Institution. There is the Institution, one and undivided. Some members live in London, some live in the Provinces, but it surely must be disastrous to the Institution if advantage can only be taken of the ability of those men who happen to live in London. For that reason I think every possible measure should be taken to enable the Local Sections to develop and to allow the Institution to take advantage of the abilities of those members who happen to live out of London.

We must make the Institution, if it is to be useful, as flexible as possible. We must be on the look-out for important questions affecting the industry and endeavour to be beforehand in catering for the difficulties which arise. I want particularly to make clear that there are certain matters which the Institution, as an Institution, cannot properly deal with, but I do not think there is any matter affecting the electrical industry which is not the business of the Institution ; that is to say, even if we cannot, as an Institution, take action in connection with some matter that arises, it is the business of the Institution to see that proper action is taken and that, if no body exists which can take that action, such a body is formed.

One matter of extreme importance has arisen during this session. I refer to the need that has become evident for combination among the staffs of central stations. It is quite clear that the Institution as an Institution cannot form an Association or act as an Association which could look after the interests of the central station staffs ; but the Council, or rather I personally, have met a Committee which was formed to found such an Association, and the Council, as a result of that interview, have decided to further in every possible way its formation. The *modus operandi* is that at a very early period there will be called in connection with each Local Section a mass meeting of, not necessarily members of the Institution, but members of the staffs of supply undertakings, to consider the desirability of forming such an Association. Those mass meetings in connection with the Local Sections will be asked to appoint delegates to attend a mass meeting in London, at which I have every confidence this Association will be started. Its object will be to look after the material interests of its members, and it will be proposed that membership of that Association should be based upon membership of the Institution ; that is to say, that members of the Association must be corporate members, in one class or another, of the Institution of Electrical Engineers. There will be a further class known as Associate Members, who need not be, and who are not, members of the Institution but who possess certain qualifications which will be defined. There is another section, the manufacturers' staffs, in regard to whom the Institution has similarly been approached, and I am confident that before long we shall be able to organize a similar Association for the manufacturing staffs.

I want to make it quite clear that these Associations are entirely distinct from the Institution, because the Institution cannot possibly fulfil the requirements that such Associations must fulfil. An Association to be recognized by the Government must have only definite circumscribed aims, and the aims of the Institution are much too catholic and too wide to enable it to act itself as these Associations, but I think by assisting in every way, by countenancing these Associations, by putting the experience of the Institution Council at the service of those forming the Associations in the early stages, the Institution is fulfilling its mission of looking after the industry and doing it in the most efficient way possible.

I have referred several times to the Local Sections and I should like to say a little more about them. The Council have set up a special Committee to consider in detail how best to extend the activities of the Local Sections. To begin with we hope to call them by a more appropriate name than Local Section. It is to be hoped that powers will be delegated to these Local Sections more especially in regard to carrying out researches in those districts which are peculiarly adapted to the particular research in view. There are districts in the country where facilities exist for production and for testing, which can nowhere else be so satisfactorily found, and the proper way of dealing with these researches seems to be to appoint local sub-committees which will take up and fully develop the matters delegated to them and report to the main Research Committees in London.

Another very important work that we hope the Local Sections will carry out is that which is already carried out in a large measure in Manchester, viz. the promotion of co-operation among other engineering bodies and branches of engineering bodies. In Birmingham there is a strong feeling in favour of this, and the Council is fostering it in the hope that good results will accrue ; similarly in Newcastle, and I have no doubt in all the other centres.

I am keenly interested in the question of proportionate representation on the Council. Under our existing Articles it is impossible to arrange for that because we have no means of controlling the way in which the election of new candidates is carried out at the ballot, but this year the Council divided up the interests of the Institution into a certain number of heads, and voted for the new nominations separately under each head, so as to secure the desired number of nominations for each interest. The result was that if the Council nominees were in fact elected to the Council, we should have a well-balanced Council, but that scheme breaks down at the ballot because it is not possible to put before the general body of members the same means of subdividing the votes as we adopted on the Council. Further, the Local Sections send their seven Chairmen to the Council and there is no guarantee that these

seven members will not all represent one interest. Of course they never do, but they might. In other words, however careful we may be to maintain the balance among the members of Council elected in the ordinary way, we cannot control in any way the interests which are represented by the Chairmen of the Local Sections.

One word as to the next session. Some things which I have advocated it has not been found possible to realize this year, but I do not see why they should not be next. One thing which I had very much at heart was an attempt to interest the general public in the work of the Institution by the giving of popular lectures. You are all familiar with the lectures given in London at the Royal Institution about Christmas time. They have been given for many years past; they are a unique affair. I do not think we should have much prospect of success if we attempted to institute lectures of the kind in London, because we should have the competition, so to speak, or rather we should be attempting to enter the field so splendidly covered, for many years past, by the Royal Institution. So far as I am aware there is nothing of that sort in this district, and I commend most heartily and earnestly to the Local Section the question of organizing next year a series of three or four lectures of the kind by some prominent men who have the gift of giving these popular lectures. I believe that if properly organized these lectures would be extremely popular in the city and it would certainly be a very excellent way of bringing the Institution before the general public.

Another allied matter is the giving of lectures, as distinct from papers, to members of the Institution on specific branches of work. As I said in my Inaugural Address, many of us would be extremely glad if we could have presented to us, by an expert on the subject, a résumé of some newly developed branch of electrical work—for example, electric furnaces. If we could have a full account of all that has been done in that direction brought before the members of the Institution by somebody who was a past master in the subject, one of the leaders in that particular branch, it would be of great benefit.

I feel very keenly that the Institution has suffered from the publicity which it has experienced at the hands of, at all events, one section of the electrical Press. For some reason which I cannot fathom, nothing which the Institution does can possibly meet with the approbation of a section of the Press and everything it does meets with their disapprobation. If the Institution happens to do something which that particular section of the Press advocates, then its having done so is practically ignored. I do not understand the reason. Another section of the electrical Press is to a very large extent lukewarm about the Institution and seldom refers to it. I believe if the Institution cannot get properly treated in the technical Press it will have no choice but to develop greatly its *Journal* and create a Press for itself. A very great deal might be made of the *Journal*. I should like to see it greatly enlarged and run very much on the lines of a publication whose name I will not pronounce because it is German, but I will simply call it the E.T.Z. All of us must feel the need for some publication in which we could find everything that really mattered for us to know, without having to dig through the enormous amount of verbiage, repetition, etc. Many members, I am afraid, are in the habit of putting away the *Journal* without opening the covers, but if they knew they were going to find a lot of interesting matter which they ought to know in order to keep up to date, I am inclined to think that the covers would not only be opened but would be very well thumbed. We have made a very humble attempt at rendering the *Journal* more interesting by adding a few pages which are distinct from the general body of the publication, and members who have opened the covers will have found more there than they expected to interest them. I should like to see that developed materially.

(Other matters touched on by the President were: the British Engineers' Association; Engineers' Clubs; a Royal Charter, and correspondingly enlarged scope, for the Institution; action by the Council concerning Fuel Oil; the Patents Bill; formation of an Electrical Cooking Association; Research; the Electrical Training Organization; and the National Electrical Proving House.)

On the motion of the Chairman, a vote of thanks to the President was unanimously passed.

Military Honours Awarded.

(Tenth List.*)

Distinguished Service Order.

McNaughton, Lieut.-Col. A. G. L.	Canadian Field Artillery	Associate Member
Pitkeathly, Major J. S., C.V.O.	General List	Associate Member

Military Cross.

Lawrence, Lieut. F. C.	West Yorkshire Regt.	Student

Bar to Military Cross.

Denison, Captain H. A.	King's Royal Rifle Corps	Student

Military Medal.

Newell, Sergt. C. A.	London Electrical Engineers, R.E.	Graduate

Order of St. Stanislas (3rd Class).

Hay, Captain P. S.	Staff	Associate Member

Croix de Guerre (Belgian).

Payne, Major F. G., D.S.O.	Machine Gun Corps	Associate Member

Mentioned in Despatches.

Payne, Major F. G., D.S.O.	Machine Gun Corps	Associate Member

* See *Journal I.E.E.*, vol. 51, pp. 306, 518, and 674; vol. 55, pp. 56, 192, 325, and 537; and *Institution Notes*, No. 1, p. 3; No. 4, p. 15.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 7. JUNE 1918. INSTITUTION NOTES. [ISSUED WITH No. 275 OF THE JOURNAL.]

Council for the Year 1918–19.

The result of the ballot for the vacancies which will occur in the offices of President, Vice-Presidents, Honorary Treasurer, and Ordinary Members of Council on the 30th September, 1918, was reported at the Ordinary Meeting on the 23rd May, 1918, to be as follows :—

President: C. H. Wordingham.
Vice-Presidents: W. A. Chamen and R. A. Chattock.
Honorary Treasurer: J. E. Kingsbury.
Ordinary Members of Council: H. W. Clothier, D. N. Dunlop, Sir R. A. Hadfield, Bart., F.R.S., Prof. E. W. Marchant, D.Sc., C. C. Paterson, O.B.E., and J. Sayers.

The Council for the year 1918–19 will therefore be constituted as follows :—

President.

C. H. WORDINGHAM, C.B.E.

The Past Presidents.

Vice-Presidents.

W. A. Chamen. G. W. Partridge.
R. A. Chattock. W. B. Woodhouse.

Honorary Treasurer.

J. E. Kingsbury.

Ordinary Members of Council.

L. B. Atkinson. G. H. Nisbett.
J. O. Callender. C. C. Paterson, O.B.E.
H. W. Clothier. W. Ll. Preece.
F. W. Crawter. W. R. Rawlings.
J. Devonshire. J. Sayers.
D. N. Dunlop. Sir W. Slingo.
Sir R. A. Hadfield, Bart., F.R.S. Colonel H. C. Sparks, D.S.O., M.C.
H. H. Harrison. A. P. Trotter.
J. S. Highfield.
Prof. E. W. Marchant, D.Sc.

and

The Chairman and Immediate Past-Chairman of each Local Section.

Benevolent Fund.

Mr. W. Lang and Sir W. Slingo have been appointed by the Council to be members of the Committee of Management of the Benevolent Fund in place of Dr. Alexander Russell and Sir John Snell.

List of Members.

In view of the scarcity and high price of paper, the "List of Officers and Members" will not be published this year. A number of copies of the List issued last year are still available, and members wishing to have a copy can obtain one on application to the Secretary.

Inventions, Researeh, and Experiments.

At the request of the Admiralty a Committee of the Institution has been formed to assist in connection with Inventions, Research and Experiments. The Committee is prepared to receive confidential suggestions from members of the Institution. All such proposals should be addressed to the Secretary, The Institution of Electrical Engineers, 1 Albemarle Street, London, W. 1.

The Committee is also prepared to receive applications from men of suitable technical training and practical test-room experience in manufacturers' works, also from those possessing skill and experience in instrument design, with a view to their employment on experimental work under the Admiralty. Preference will be given to men who have served and are unfit to serve in the Forces. No fit man under 26 years of age will be eligible.

Applications, stating age, with full particulars of training and experience and remuneration required, should be made to the Secretary, The Institution of Electrical Engineers, 1 Albemarle Street, London, W. 1.

Prize for Paper on the Co-ordination of Research in Works and Laboratories.

The Council are prepared to receive papers on the subject of "The Co-ordination of Research in Works and Laboratories," with a view to the paper being read and discussed at one of the Ordinary Meetings of the Institution in London, and also before one or more of the Local Sections. Papers should not exceed 15,000 to 20,000 words in length, and the Council are prepared to award a special premium of £25 to the author of the paper which in their judgment best fulfils the objects of the discussion, provided

such paper reaches the standard aimed at by the Council.

Papers should be sent to the Secretary of the Institution not later than the 4th November, 1918. It is the intention of the Council to publish the selected paper (which will become the property of the Institution) in the *Journal* together with the discussion. Competitors intending to submit papers are invited to communicate with the Secretary.

Maintenance Agreements for Secondary Batteries.

The Council will shortly appoint a Committee to draw up Standard Conditions for Maintenance Agreements in connection with Secondary Batteries.

Fuel and Lighting Order, 1918.

A deputation consisting of representatives of the Institution, the various Electricity Supply Associations, the B.E.A.M.A. and others, has been received twice by the Deputy Coal Controller in connection with the proposed Fuel and Lighting Order. As a result satisfactory modifications have been embodied in the Order.

Overseas Engineering Trade.

The Council have arranged to hold, under the Chairmanship of the President of the Institution or one of the Vice-Presidents, a conference of representatives of interested bodies to consider the formation of a co-operative organization to deal with Overseas Engineering Trade.

Electrical Cooking and Heating Association.

The Council have also appointed a Committee, consisting of representatives nominated by interested bodies, to prepare a detailed scheme for the formation of an Electrical Cooking and Heating Association.

Register of Members on War Service.

The Council have decided to open a Register of members who have joined the Navy or Army or who have otherwise relinquished their pre-war posts for special war work (such as munitions, etc.), with a view to helping those who may desire assistance on their return to civil life in regaining the positions they previously held, or in obtaining other suitable posts. Any such member who wishes his name to be included in this Register, and who has not already received from the Institution an inquiry form in regard to his previous training and experience, should apply to the Secretary for a copy.

Electrical Appointments Board.

The Council have also decided to set up an Electrical Appointments Board similar to the Civil Engineers' Appointments Board. Particulars will be published as soon as they are available.

Portrait of Galileo.

Owing to the difficulty of obtaining a satisfactory reproduction of the Galileo portrait (see *Institution Notes*, No. 5, p. 18) it has been decided to postpone for the present the issue of copies of the portrait with the *Journal*.

National Electrical Proving House.

The Council have appointed a Committee, consisting of representatives of interested bodies, to prepare a detailed scheme for an Electrical Proving House.

At the Ordinary Meeting of the Institution on the 9th May, 1918, the President (Mr. C. H. Wordingham) in making the above announcement said :—

"The Council have asked me to give a brief account of their attitude on this subject before the discussion begins. As I think most of the members are aware, I made certain suggestions over 20 years ago in connection with the foundation of such an institution as is now referred to as a National Electrical Proving House. Nothing came of that suggestion; but about three or four years ago I made a similar suggestion to the Council, and it went before the old Industrial Committee. But the war broke out and it was not feasible to do anything in the matter then. We have now had brought before us this paper by Mr. Turnbull, in which he outlines a very comprehensive and, I must say, a very ambitious scheme. That there is a need for a Proving House is, I think, now very generally admitted, but it is important that one should define exactly what one means by a Proving House, and what the Council is prepared to support in the direction of establishing a Proving House. It is of vital importance that we should not establish a new body to do work which is already being done by some other body, and the Proving House should be just what its name indicates—namely, an institution which will ascertain by test whether an article actually is what it purports to be. Therefore, such an institution would exclude from its purview research properly so called. Of course, one cannot make tests without in a certain sense conducting a research, because every test one makes is an inquiry into the nature of the article, as to whether it does or does not do certain things. But so far as research properly so called is concerned, we do not think that the National Proving House should cover that ground. Then,

again, it is important to remember that it is a commercial kind of testing with which it deals. It is not concerned with matters of high accuracy such as are dealt with properly by the National Physical Laboratory. Again, the Proving House is not the authority, in our judgment, to formulate rules or to issue standard or other specifications. Its function is merely to see whether rules laid down by the competent authorities are or are not complied with, and whether specifications issued by competent authorities are or are not conformed to. Members may think that its scope is rather circumscribed, but I venture to think that even in that circumscribed scope there will be a very large field of activity, and that it will carry out its work much more efficiently for concentrating on that particular branch of work, which is not at present covered by any other institution, rather than by spreading itself over a wide field, which would overlap the activities of other institutions very much better qualified to perform the work. Another essential feature of the Proving House is this. The primary object of the Proving House being the promotion of the interests of British manufacturers, it is essential that it should affix its hall-mark only to articles of British, or perhaps I would rather say, in order to make my meaning quite clear, Imperial manufacture. The importance of this is great, because those of us who are keen upon the foundation of this Proving House feel that it should provide a hall-mark which implies that the article to which that hall-mark is affixed is made within the Empire, and that it has reached the high standard of excellence which we hope always to see associated with Imperial products.

"Now as to the way in which this Proving House is to be set on foot. I confess frankly that until quite recently I was of opinion that it should be an entirely independent body, and my reasons for thinking so were that I felt that if it were to be a success, the management must be vested in a Board on which manufacturers would be largely represented, though not preponderant. The commercial element must be present in preponderating amount, and manufacturers must be represented in a large proportion, and also users and other authorities such as consulting engineers and municipal and company authorities, and so on. I felt that if it were attempted to found this National Proving House as a sort of offshoot of the National Physical Laboratory it would be impossible to have this commercial control, and there would be danger that the certificates issued would be regarded as being of an academic nature. But the war has effected great changes in the National Physical Laboratory, as well as in so many other things, and I find that it has been lately carrying out a large amount of commercial testing, notably in connection with glass-ware for chemical purposes, and, further, that it has been found possible and expedient to set up Advisory Boards in connection with the Laboratory, in which commercial interests are largely represented. That entirely removes the objections which I had until quite lately. The Laboratory, as members know, is now to all intents and purposes a Government Department and is under the control of the Advisory Council of Scientific and Industrial Research. It will have ample funds at its disposal and it is progressing in this way with the requirements of British trade. The Council is firmly convinced that the Proving House could be formed as an offshoot of the National Physical Laboratory, subject to the management of the Proving House being in the hands of a Board constituted on thoroughly representative lines, forming, as it were, a sort of Sub-Committee of the National Physical Laboratory, whose Committee must, of course, be the overriding and ruling authority, but this Board would have weighty powers delegated to them by the National Physical Laboratory Committee.

"I should like to mention the constitution of the Main Governing Body of the Proving House, such as is suggested as suitable by the Council. There would be three representatives of the Institution of Electrical Engineers, of whom one would be the President for the time being; six representatives of the B.E.A.M.A., each from a different section, excluding cable makers; one representative of the Cable Makers' Association; two representatives of other Associations representing particular manufacturing interests; two representatives of the I.M.E.A; three representatives of Power Companies and Supply Companies; two representatives of the Electrical Contractors' Association; two representatives of the Fire Insurance Companies; one representative of the Shipping Insurance Companies; one representative of the Tramways Association; two representatives of Electrical Consulting Engineers; two representatives of the Engineering Standards Committee; one representative of the National Physical Laboratory; one representative of the professorial staff of Technical and Engineering Colleges; two representatives of large purchasers such as Railway Companies and Docks, etc.; one representative of Exporters (Merchants) of Electrical Plant; and six representatives of Government Departments; making a total of 38. That, of course, would be an entirely unworkable Committee to look after the actual business, and it is suggested that from those there should be elected a Committee of 11, three representing manufacturers; one the wiring contractors; two the Institution of Electrical Engineers; one the Government Departments; one Municipal Authorities; one Public Supply Authorities; one Fire Offices; and one Consultants. That is, of course, only a suggestion, but it gives an idea of the scope that we think this governing body, under the Committee of the National Physical Laboratory, should have.

"In conclusion I should like to say that I think further great advantages of establishing the Proving House in connection with the National Physical Laboratory are that unquestionably it must have very much greater prestige if it has the National Physical Laboratory behind it, and I believe there is little doubt that if established on these lines it is infinitely more likely to secure Government support and Government recognition than if it were put forward on a separate basis."

Students' Section.

The following is an abstract of the Report of the Committee for the Session 1917–18, which was adopted at the Annual General Meeting of the Students' Section on the 15th May, 1918:—

During the session there have been 8 Meetings, in addition to the Annual General Meeting. Owing to the taking over of the Institution building by the Government

it has been necessary to hold the Meetings at various Colleges in London. There has been a considerable increase in the attendances at the Meetings, the average attendance being 52, and the highest recorded during the Session 185.

An Address, entitled "Astronomical Applications of the Electrical Theory of Matter," was delivered to the Section on the 23rd November, 1917, by Sir Oliver Lodge, F.R.S.

The President (Mr. C. H. Wordingham) also addressed the Section on the 22nd March, 1918, dealing in his remarks with labour problems and the organization of the engineering profession.

Electric Power Supply.

The Report (Cd. 9062) of the Committee appointed by the Board of Trade in March, 1917, to consider the question of electric power supply has recently been issued.

The constitution of the Committee was as follows :—

Sir Archibald Williamson, Bart., M.P. (*Chairman*), H. Booth, O.B.E., J. F. Crowley, D.Sc., J. Devonshire, H. Dickinson, J. Falconer, M.P., G. H. Hume, J. Kemp, E. F. Vesey Knox, K.C., H. H. Law, C.B., C. H. Merz, The Hon. Sir Charles Parsons, K.C.B., F.R.S., W. B. Smith, O.B.E., Sir John Snell, Alderman C. F. Spencer, A. J. Walter, K.C., M. J. Collins (*Secretary*).

And the terms of reference were :—

"To consider and report what steps should be taken, whether by legislation or otherwise, to insure that there shall be an adequate and economical supply of electric power for all classes of consumers in the United Kingdom, particularly industries which depend upon a cheap supply of power for their development."

On the 14th May, 1917, the Committee came to the following preliminary conclusions :—

(1) That when British industry is subjected to the test of keen international competition after the war, its success will depend upon the adoption of the most efficient methods and machinery, so as to reduce manufacturing costs as much as possible.

(2) That a highly important element in reducing manufacturing costs will be the general extension of the use of electric power supplied at the lowest possible price, and it is by largely increasing the amount of power used in the industry that the average output per head, and, as a consequence, the wages of the worker, can be raised.

(3) That the present system under which a supply of electricity is provided in a large number of small areas by separate authorities, is the result of a policy adopted at a time when the applied science of electrical engineering was in its infancy, and is incompatible with anything that can now be accepted as a technically sound system.

(4) That the interconnection of existing electrical supply stations, recommended by the Board of Trade in their letter of the 25th May, 1916, however desirable in itself, cannot alone meet the requirements of the situation.

(5) That a comprehensive system for the generation of electricity, and, where necessary, re-organizing its supply, should be established as soon as possible.

In their final Report, in addition to re-affirming the above conclusions, the Committee make, subject to conditions set out in the Report, a number of recommendations, which are summarized as follows :—

(*a*) That a new body to be called the Electricity Commissioners should be set up, to whom should be transferred the existing powers of the Board of Trade, Local Government Board, Local Government Board for Ireland, and Scottish Office, relating to the supply of electricity, and to whom large additional powers should be given for regulating and encouraging the generation and distribution of electricity.

(*b*) That the Electricity Commissioners should, subject to an appeal to Parliament in certain cases, have general control over the generation and distribution of electricity in the United Kingdom.

(*c*) That the existing system under which electricity is separately generated for small areas should be abolished.

(*d*) That the Electricity Commissioners should, after local inquiries, divide the United Kingdom into districts technically suitable for the economical generation and distribution of electricity.

(*e*) That in each electrical district a District Electricity Board should be set up which should purchase all generating stations of authorized distributors, whether local authorities, companies, or power companies.

(*f*) That the District Electricity Board should be responsible, by themselves or their lessees, for the future generation of electricity in their district and for the establishment of new generating stations and proper systems for the main transmission of electricity in their district.

(*g*) That existing electrical undertakers should, if they so desire, retain their power of distributing electricity within their local areas, but should purchase electricity in bulk from the District Electricity Boards or their lessees, due provisions being made for controlling the profits of distributors so as to ensure a cheap supply of electricity to consumers.

(*h*) That District Electricity Boards should make no divisible profits.

(*i*) That District Electricity Boards should be financed, in whole or in part, by funds raised with Government assistance, except where it is shown to be desirable and practicable to finance the Boards locally.

(ii) That largely extended powers should be granted for, *inter alia*—

(i) The use of overhead wires.
(ii) Wayleaves.
(iii) Acquisition of water rights.

The Report places on record the valuable assistance afforded to the Committee by the personal evidence of the following witnesses :—

Mr. Lewis Beard, Town Clerk of Blackburn : Mr. C. N. Hefford, Manager of the City of Leeds Electricity Department ; Mr. R. A. Reay-Nadin, Town Clerk of Sutton Coldfield. *Representing.*—Association of Municipal Corporations.

Sir Harry Haward, Controller. *Representing.*—London County Council.

Mr. W. P. Nicholas, Clerk of the Rhondda Urban District Council ; Mr. A. H. Dykes, Hon. Secretary of the Association of Consulting Engineers. *Representing.*—Urban District Councils' Association.

Mr. Alexander Stevenson, Councillor of the City of Edinburgh, and ex-Convener of the Electric Lighting Committee. *Representing.*—Convention of Royal Burghs of Scotland.

Mr. W. B. Woodhouse, Engineer and Manager of the Yorkshire Electric Power Company. *Representing.*—Incorporated Association of Electric Power Companies.

Mr. C. P. Sparks, President of the Institution of Electrical Engineers (1917). *Representing.*—Institution of Electrical Engineers.

Mr. H. Faraday Proctor, Hon. Secretary of the Incorporated Municipal Electrical Association. *Representing.*—Incorporated Municipal Electrical Association.

Mr. S. L. Pearce, Chief Engineer and Manager of the Manchester Corporation Electricity Department. *Representing.*—Committee for the Interconnection of the Lancashire and Cheshire Electricity Supply Systems.

Mr. D. A. Starr, General Manager of the Clyde Valley Electrical Power Company. *Representing.*—Association of County Councils in Scotland.

Mr. Henry Riddell, Councillor of the City of Belfast. *Representing.*—Municipal Authorities in Ireland.

Mr. Roger T. Smith, Electrical Engineer to the Great Western Railway ; Mr. Philip Dawson, Consulting Electrical Engineer to the London, Brighton and South Coast Railway. *Representing.*—Railway Executive Committee.

Mr. A. S. Blackman, Electrical Engineer to the Corporation of Sunderland. *Representing.*—Six Corporations supplying electricity on the North-East Coast.

Mr. L. L. Robinson, Electrical Engineer to the Borough Council of Hackney. *Representing.*—Authorities of Greater London owning electricity undertakings.

Mr. G. Marshall Harriss, General Manager of the Dublin United Tramways Company, Limited. *Representing.*—Electric Supply Companies in Ireland.

Mr. W. F. Fladgate, M.V.O., Chairman of the Charing Cross, West End and City Electricity Supply Company, Limited ; Sir Alexander Kennedy, F.R.S., Engineer-in-Chief to several London Electric Supply Companies. *Representing.*—London Electric Supply Companies.

Mr. W. C. Thorne, Solicitor ; Mr. T. M. Newell, Engineer-in-Chief. *Representing.*—Mersey Docks and Harbour Board.

Mr. W. H. Hannay, Councillor of the City of Glasgow ; Mr. W. W. Lackie, Engineer and Manager of the Electricity Department of the City of Glasgow. *Representing.*—Conference of nine Municipalities in the West of Scotland.

Mr. R. P. Sloan, Director and Manager of the Newcastle-upon-Tyne Electric Supply Company, Limited. *Representing.*—North-East Coast Electric Power Companies.

Mr. Arnold B. Gridley, Director of Electric Power Supply of the Ministry of Munitions. *Representing.*—Ministry of Munitions.

Mr. H. B. Renwick, Managing Director of the County of London Electric Supply Company, Limited, and other Companies, also Chairman of the Provincial Electric Supply Committee of the United Kingdom. *Representing.*—Provincial Electric Supply Committee of the United Kingdom.

Captain H. Riall Sankey, C.B., R.E. *Representing.*—Federation of British Industries.

Mr. J. P. Crosbie, Director and Works Manager. *Representing.*—Messrs. Hadfields, Limited, of Sheffield.

Sir John A. F. Aspinall, General Manager of the Lancashire and Yorkshire Railway. *Representing.*—Railway Companies' Association.

Mr. D. Milne Watson, Managing Director of the Gas Light and Coke Company, and Chairman of the Executive Committee of the National Gas Council ; Mr. H. E. Jones, President of the Institution of Civil Engineers and President of the National Gas Council. *Representing.*—National Gas Council.

Mr. J. S. Highfield, Consulting Engineer to the Metropolitan Electric Supply Company, Limited, and other Companies.

The Committee also had written evidence from Mr. M. Ruddle, Electrical Engineer to the Corporation of Dublin, and Mr. J. F. Delany, Engineer to the Corporation of Cork, representing Municipal Authorities in Ireland, and had before them the evidence given before the Electrical Trades Committee by Mr. Stephen Sellon on behalf of the Tramways and Light Railways Association.

The report may be obtained through any bookseller or directly from H.M. Stationery Office, price 3d.

Roll of Honour.

(Tenth List.*)

Killed in Action.

Andrews, Captain G. L.	Royal Garrison Artillery	Member
Hurlbatt, Captain E. S., M.C.	Manchester Regiment	Associate Member
MacIndoe, Private G.	New Zealand Signal Section	Graduate
Turner, Captain H. E.	Royal Garrison Artillery	Associate Member

* See *Journal I.E.E.*, vol. 54, pp. 61, 447, and 675 ; vol. 55, pp. 55, 193, 348, and 537 ; and *Institution Notes* No. 1, p. 3 ; No. 4, p. 15.

Died of Wounds.

Powell, Captain C., M.C.	Royal Engineers	Associate Member

Accidentally Killed.

Hyde-Thomson, Lieut.-Col. D. H.	Royal Air Force	Associate Member

Military Honours Awarded.

(Eleventh List.*)

Distinguished Service Order.

Spier, Lieut.-Col. K. R. N.	Royal Engineers	Associate Member

Military Cross.

Dillon, Lieut. T. F.	Royal Engineers	Associate Member
Aspland, Captain G. D.	Royal Engineers	Graduate
Collyer, 2nd Lieut. G.	Royal Engineers	Graduate
Andersen, Lieut. R. C.	Royal Engineers	Student
Bicknell, Captain C. R.	Royal Garrison Artillery	Student
Brazel, Major C. H.	Royal Engineers	Student
Clark, Lieut. R. M.	Royal Engineers	Student
Colston, 2nd Lieut. C. B.	Royal Engineers	Student
Hannam-Clark, Captain H. C.	Royal Engineers	Student
Williams, Lieut. C. S.	Royal Engineers	Student

Members on Military Service.

(Sixteenth List.†)

Members.

Name.	*Corps, etc.*	*Rank.*
Jackson, D. C.	United States Army	Major
Watson, C. G.	Royal Engineers	Sergeant

Associate Members.

Bellamy, R. F.	Royal Air Force	Captain
Brotheridge, T. R.	Royal Navy	Com. Elect.
Ditcham, W. G.	R.N.V.R.	Lieut.-Com.
Dixon, A. O. St. J.	Royal Marines	Lieutenant
Greenwood, H. C.	Indian Army Reserve of Officers	Lieutenant
Harding, P. H.	London Regiment	Private
Hooper, H.	Royal Engineers (attd. R.A.F.)	Lieutenant
Hughes, A. E.	Royal Engineers	Captain
Jarvis, E. J.	Royal Engineers	Lieutenant
Jones, E. W.	Royal Engineers	2nd Lieut.
Manson, J. C.	Canadian Engineers	Lieutenant
Roberts, W	Royal Field Artillery	Major
Sergent, R. S. B.	R.N.V.R.	Sub.-Lieut.
Sherratt, T., Jr.	R.N.V.R.	Assistant Paymaster
Slingo, P. E.	Royal Engineers	Captain

* See *Journal I.E.E.*, vol. 54, pp. 306, 518, and 674; vol. 55, pp. 56, 193, 325, and 537; and *Institution Notes*, No. 1, p. 3; No. 4, p. 15; No. 6, p. 24.

† See *Journal I.E.E.*, vol. 53, pp. 199, 326, 388, and 857; vol. 54, pp. 121, 403, 518, and 675; vol. 55, pp. 57, 194, 326, and 538; and *Institution Notes*, No. 1, p. 4; No. 4, p. 16; No. 5, p. 18.

Associate Members—*continued.*

Name.	*Corps, etc.*	*Rank.*
Tamblyn-Watts, T. M. F.	Royal Flying Corps	2nd Lieut.
Vivian, G. H. F.	London Regiment	Private
Watson, E. C.	Royal Navy	Lieut.-Com.
Widdicombe, R. A.	Royal Engineers	Major
Woods, E. F.	Australian Flying Corps	Lieutenant

Associate.

Munro, H. N.	Royal Air Force	2nd Lieut.

Graduate.

Lebedeff-Lessin, M. A.	Royal Engineers	Pioneer

Students.

Beckett, T. R.	Royal Garrison Artillery	Signaller
Bickell, S. F.	Royal Navy	Elec. Artificer
Budgen, H. P.	Royal Navy	Elec. Eng.
Champney, L.	Royal Engineers	Sapper
Hall, H. J.	Royal Air Force	3rd-Class Air Mechanic
Hughes, H. G.	Army Service Corps	Private
Ibeson, W.	Royal Navy	Wireman
Jennings, J. S.	Royal Engineers	Pioneer
Lye, D. H. C.	Royal Air Force	Lieutenant
Morris, A. J.	Royal Engineers	Pioneer
Norris, E. D. T.	Royal Engineers	Cadet
O'Neill, J. F.	R.N.V.R.	Sub.-Lieut.
Orchard, H. L.	Royal Engineers	Sapper
Porter, A. G.	Royal Garrison Artillery	Major
Steele, W. H.	Royal Air Force	1st-Class Air Mechanic
Thomas, L.	Royal Air Force	3rd-Class Air Mechanic

Promotions, Transfers, etc., of Members on Military Service.

(Twelfth List.*)

Members.

Name.	*Corps, etc.*	*Rank.*
Butters, J. H.	Australian Engineers	Major
Coales, J. D.	Royal Air Force	Lieutenant
Erskine-Murray, J.	Royal Air Force	Major
Haslam, S. B.	Royal Engineers	Lieutenant
Leaf, H. M., D.S.O.	Royal Marine Artillery	Major
Morcom, R. K.	Royal Engineers	Major
Pooley, F.	R.N.V.R.	Chief Petty Officer

Associate Members.

Anderson, S. D.	Royal Engineers	Captain
Ballard, L. W.	Royal Engineers	Captain
Barney, L. W.	Royal Air Force	Captain
Barton, R. G.	Staff for R.E. Services	Lieutenant
Baynham, H. P.	Royal Marines	Lieutenant
Bedford, J. R.	R.N.V.R.	Sub-Lieut.
Bennett, H. B.	Indian Army Reserve of Officers	Captain
Browne, W. S.	London Electrical Engineers, R.E.	Lieutenant
Coates, W. H. C., M.C.	Royal Field Artillery	Major

* See *Journal I.E.E.*, vol. 54, pp. 307, 404, 579, and 675; vol. 55, pp. 59, 95, 327, and 539; and *Institution Notes*, No. 2, p. 8; No. 3, p. 11; No. 5, p. 19.

ASSOCIATE MEMBERS—*continued.*

Name.	*Corps, etc.*	*Rank.*
Driver, E. T.	Royal Air Force	Lieutenant
Fidoe, J. W.	Royal Engineers	Captain
Fulcher, E. W. P.	Royal Engineers	Lieutenant
Hill, F. A.	London Electrical Engineers, R.E.	2nd Lieut.
Hollings, G. A.	Royal Engineers	Lieutenant
Hunstone, W. H.	Embarkation Staff	Captain
Loughlin, H. J.	Royal Engineers (attd. R.A.F.)	Lieutenant
McMahon, V. H. M.	Army Service Corps	Lieutenant
Maguire, C. E.	Royal Engineers	Captain
Mallinson, G. G.	Royal Garrison Artillery	Major
Murray, J. B.	Royal Engineers	Lieutenant
Paton, G.	Army Ordnance Department	Captain
Paul, R. B.	Royal Engineers	Lieutenant
Preston, E. B. C.	Wildes Rifles (India)	Captain
Pyne, F. D.	Royal Engineers	Major
Robertson, C. E.	Army Service Corps	2nd Lieut.
Rorke, A., M.C.	Royal Engineers	Captain
Russell, W. E.	London Electrical Engineers, R.E.	Sergeant
Scampton, G. O.	London Electrical Engineers, R.E.	Corporal
Shepheard, H. B.	Royal Air Force	2nd Lieut.
Stephens, J. N.	Royal Air Force	Captain
Sykes, G.	R.N.V.R.	Lieutenant
Turner, S.	Royal Air Force	Lieutenant
Walsh, B. P. K.	Royal Air Force	2nd Lieut.
Williams, E.	Royal Engineers	Lieutenant
Wilson, A. L.	Royal Air Force	Lieutenant
Winkworth, L. S.	Tyne Electrical Engineers, R.E.	Lieutenant
Wood, D. S.	Royal Engineers	2nd Lieut.

ASSOCIATES.

Ditmas, F. I. L., D.S.O., M.C.	Durham Light Infantry	Lieut.-Col.
Nash, E. A.	Royal Air Force	Captain

GRADUATES.

Girdlestone, H.	Royal Air Force	Captain
Orme, B. S.	Royal Engineers	Lieutenant
Sedgwick, A. J.	Royal Engineers	Corporal
Wilkin, D.	Tank Corps	2nd Lieut.
Wybrow, S. G.	Royal Air Force	Captain

STUDENTS.

Chapman, E. D.	Royal Air Force	Corpl.-Mech.
Elsden, G. H.	London Electrical Engineers, R.E.	Lance-Corpl.
Felix-Smith, L. E.	Army Service Corps	Lieutenant
Haigh, G.	Royal Engineers	2nd Lieut.
Heyes, F. J.	Royal Anglesey, R.E.	Lieutenant
Hindom, H. J.	Royal Air Force	1st-Class Air Mechanic
Hitch, A. T.	Bedfordshire Regt.	Major
Hyde, C. L. G.	Royal Engineers	Cadet
Jepson, C.	Royal Air Force	Corpl.-Mech.
Morris, C. I.	Machine Gun Corps	Captain
Pryce, S. E. T.	Royal Garrison Artillery	Captain
Thornton, C. V.	Royal Air Force	Lieutenant
Williams, C. S., M.C.	Royal Engineers	Lieutenant
Wood, P. J.	Royal Engineers	Lieutenant
Wust, A.	Belgian Wireless Telegraphy Corps	Engineer

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Ministry of Munitions. Health of the munition worker.
8vo. 138 pp. *London*, 1917

Ministry of Munitions of War. Munitions Inventions Dept. The nitrogen problem, and the work of the Nitrogen Products Committee.
8vo. 14 pp. *London*, 1917

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8vo. 217 pp. *Philadelphia*, [1917]

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8vo. 166 pp. *London*, 1917

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8vo. 694 pp. *Toronto*, 1917

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8vo. 71 pp. *London*, 1917

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8vo. 43 pp. *Washington*, 1917

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8vo. 180 pp. *Paris*, 1918

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8vo. 188 pp. *London*, 1917

Wilson, J. F. Essentials of electrical engineering. A text-book for colleges and technical schools.
8vo. 358 pp. *London*, 1917

THE INSTITUTION OF ELECTRICAL ENGINEERS.

No. 8. July 1918. INSTITUTION NOTES. [ISSUED WITH No. 276 OF THE JOURNAL.]

Military Service Act, 1918.

The Council have been in communication with the Ministry of National Service with reference to the utilization, with due regard to their skill, of members of the Institution called up for military service under the above Act.

With a view to their being posted, as far as vacancies are available, to technical units, members of the new military age, on being called up for military service, are therefore invited to communicate with the Secretary of the Institution, who will supply them with the Form and Certificate approved by the Ministry for this purpose.

Certified Occupations.

The Secretary of the Institution has been informed by the Ministry of National Service that, as a temporary measure, instructions have been given to the Regional Officers of the Ministry not to call up for medical examination men of the new military age who are engaged in one of the occupations named below, provided they were engaged in the same occupation (not necessarily with the same employer) on or before the 15th August, 1915.

Electrical Engineering :
Foreman.
Turner; Fitter; Erector; Electrician or other skilled workman.
Wireman.

Radiography Joint Committee.

In collaboration with the British Association for Radiography and Physio-Therapy, the Council of the Institution have nominated the President (Mr. C. H. Wordingham), Mr. J. S. Highfield, Professor T. Mather, and Mr. A. A. C. Swinton to serve on a Joint Committee of the two bodies, which has been appointed to prepare a scheme for ensuring that lay radiographers, etc., are properly qualified.

Board of Trade Reports on Electric Power Supply and Electrical Trades after the War.

The Council have appointed a Committee to report on the above. The following bodies have been invited to nominate two representatives each to serve on the Committee :—

Incorporated Municipal Electrical Association,
Association of Municipal Corporations,
Incorporated Association of Electric Power Companies,
Provincial Electric Supply Committee of the United Kingdom,
Conference of Chief Officials of the London Electric Supply Companies,
British Electrical and Allied Manufacturers' Association,
Cable Makers' Association,
Tramways and Light Railways Association,
Municipal Tramways Association,
The Iron and Steel Institute,
British Electrical Federation,
Edmundsons' Electricity Corporation,
Federation of British Industries.

(The President and the four Vice-Presidents of the Institution are also members of the Committee.)

Maintenance Agreements for Secondary Batteries.

The Committee appointed by the Council to report on the above (see *Institution Notes*, No. 7, page 26) consists of :—

	Nominated by
C. H. Wordingham, C.B.E. Sir William Slingo. R. T. Smith. F. W. Crawter. R. A. Chattock.	The Institution.
D. P. Dunne. E. Jacob	The B.E.A.M.A.
(*One representative to be nominated*)	The I.M.E.A.
J. S. Highfield	The Incorporated Association of Electric Power Companies.

Local Sections.

A Committee was appointed by the Council in March 1918 to review the position of the Local Sections and to make suggestions as regards increasing their usefulness. The Report of this Committee was recently considered by the Council and as a result it has been agreed :—

(1) That the Local Sections be known in future as "Centres," their names being altered as follows :—

New Name.	*Present Name.*
North Western Centre	Manchester Local Section
North Midland ,,	Yorkshire ,, ,,
South Midland ,,	Birmingham ,, ,,
North Eastern ,,	Newcastle ,, ,,
Western ,,	Western ,, ,,
Scottish ,,	Scottish ,, ,,
Irish ,,	Dublin ,, ,,

The Irish Centre to include the whole of Ireland.

(2) To empower the Territorial Centre Committees to represent the Institution on other bodies, such as Chambers of Commerce, Technical Library Committees, Education Authorities, kindred Engineering Societies, and so forth, subject to the approval of the Council in each case.

(3) To delegate certain branches of research to some of the Territorial Centres by the formation of local Research Sub-Committees ; such Sub-Committees to be appointed by the Council at the instance of the Territorial Centre Committees. It will be the duty of each Sub-Committee to report to the Research Committee and to keep the Territorial Centre Committee informed of the progress of the particular research.

(4) To invite other bodies to co-operate through their local Associations in regard to forming local Engineers' Clubs.

Associate Membership Examination.

In view of the practical impossibility while the war continues of holding the Associate Membership Examination and of candidates having the requisite time to prepare for or undergo examination, the Council have decided to suspend temporarily the Institution rules in regard to examinations.

The greatest care will nevertheless be exercised by the Council to ensure that only candidates possessing the qualifications laid down in the Articles in respect of training and experience are admitted to Associate Membership.

Candidates who have been informed that they have been approved for Associate Membership subject to their passing the examination and who desire their applications to be reconsidered by the Council are requested to communicate with the Secretary.

Engineering Training Organization.

The Council have sanctioned, on behalf of the Institution, a contribution of £250 towards the expenses of the above Organization for 1918.

"Technical Supplement" to the Foreign Press Review.

Arrangements have been made by the War Office to place the above Supplement on sale through H.M. Stationery Office at the price of 6d. a copy.

It is desired to make the "Supplement" of the utmost use to engineers, and with this object suggestions or criticisms would be welcomed. Communications should be sent to the Editor, "Technical Supplement" to the Foreign Press Review, War Office, Embankment Annexe, S.W. 1.

Professor Righi.

The following biographical note of Professor Augusto Righi, who was elected an Honorary Member of the Institution on the 22nd November, 1917 (see *Institution Notes*, No. 1, page 1), will be of interest to members :—

Professor Righi was born at Bologna on the 27th August, 1850, and was educated in that city. He began his career as a teacher on his appointment in 1871 as Physics Assistant at the University in his native city, and two years later was appointed Professor at the Technical Institute. Subsequently he became, in 1880, Professor at the University of Palermo, and in 1885 at Padua University. In 1899 he was appointed Professor at Bologna University, a position which he still holds. He is a member of numerous Italian scientific Societies and of the principal foreign Societies, and has on three occasions been President of the Royal Academy of Sciences. He has also held the office of President of the Italian Physical Society. Most of the scientific Societies of his country have at various times awarded him important prizes, among others the King's Prize for Physics of the Accademia dei Lincei. He has also received the Hughes Medal and Prize of the Royal Society of London. In recognition of his high scientific attainments the Italian Government in 1905 nominated him a Senator of the Kingdom.

He is the author of numerous papers and works, several of which have been translated into other languages. Among the former may be mentioned those on the subject of electric waves, previous to the development of wireless telegraphy. This work placed Righi in the front rank of pioneers in connection with conduction in gases. Among his more recent work may be mentioned his investigations on the conduction of gases in a magnetic field. His published works include "A Modern Theory of Physical Phenomena."

Commercial Electrical Development Committee.

The Committee appointed by the Council to consider the formation of an Electrical Cooking and Heating Association (see *Institution Notes*, No. 7, page 26) having completed its preliminary work, a new Committee, with the above title, has been formed.

The new body, which is a separate organization independent of any Institution or Association, will immediately consider the question of the development of Electrical Cooking and Heating.

Engineers' Protective Association.

At the invitation of the Council a Conference of representatives of the Associated Municipal Electrical Engineers of Greater London, the Chief Technical Assistants' Association, and the Electrical Power Engineers' Association was held at the temporary offices of the Institution on the 9th July. The number of representatives sent by each Association was in proportion to its membership.

The chair was taken by the President, and the Council was further represented by Messrs. R. A. Chattock, G. W. Partridge, and Roger T. Smith, Vice-Presidents, and Messrs. A. H. W. Marshall, R. Howard Fletcher, and W. Lang, Chairmen of the Newcastle, Western, and Yorkshire Local Sections respectively.

At the close of the proceedings the following resolutions were passed, subject to ratification by the governing bodies of the three Associations:—

(1) That one single combined protective Association be formed for the whole electric supply industry.

(2) That Chief Engineers be included in the membership provided they are not employers or employers' representatives on an Industrial Council or similar body dealing with technical staffs, subject also to proper safeguards for special staff questions that may arise.

(3) That a protective association formed from existing associations adopt the constitution, and for the present the title, of the Electrical Power Engineers' Association, seeing that it is the only existing Association for the purposes in view which is constituted as a Trade Union.

(4) That the qualifications for membership of the Association be those of the Electrical Power Engineers' Association, but all new members elected after 31st December, 1921, shall be required to have passed the A.M.I.E.E. Examination or an equivalent examination, and that this be the link between the Institution and the Association.

(5) That the Chief Technical Assistants' Association and the Associated Municipal Electrical Engineers of Greater London each appoint two representatives to meet the National Executive Committee of the E.P.E.A. at Manchester on the 27th July to discuss and approve the draft constitution of the E.P.E.A. This draft in turn to be submitted to the Institution for final ratification. The representatives of the two Associations first named, if members of the E.P.E.A., to remain as part of the National Executive Committee of the E.P.E.A. for the current year (i.e. until June, 1919).

The Institution also to send a representative of the Council to attend the meeting of the 27th July in an advisory capacity.

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